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Cognitive Biases and the Cultural Disconnect between Engineers and Decision-makers

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Abstract. Engineering culture is alien to the way the average person thinks and makes decisions. There is a dichotomy between the evidence-based analytical methodologies used by engineers and the intuitive or heuristic processes commonly used by the general public. Both can be appropriate in context, but wrong choices can lead to undesirable and sometimes dire consequences. For the recommendations from an engineering analysis to be accepted by non-technical decision-makers, the findings must be presented in a manner that takes account of human factors. Successful engineers are those who are proficient in translating the language of their technical discipline into that of broader society. A key skill is consequential reasoning, which is contained within engineering codes of ethics but is also critical to the persuasive power of analytical findings. Students and early-career engineers need structured learning in communication and in socio-cultural and emotional intelligence. They need exposure to cognitive psychology and epistemology, especially in relation to bias and false logic. If formal humanities courses cannot be accommodated in the undergraduate engineering degree, then post-graduate and continuing professional development opportunities should be offered.

Keywords. Behavioural Engineering, Cognitive Bias, Consequential Reasoning, Critical Thinking, Decision Analysis, Socio-cultural intelligence

1. Introduction and Objectives

"The whole problem with the world is that fools and fanatics are so certain of themselves, yet wiser people so full of doubts."
3rd Earl Bertrand Russell, *The Triumph of Stupidity*, 1933.[1]

The typical role of an engineer can be described as the collection and analysis of technical data, leading to judgements about the most favourable set of parameters to ensure optimal performance of a machine, structure, or system. However, the final decisions in such matters are often made by people other than those who have performed the analysis. Therefore, a major task for the engineer is to so communicate the methods of analysis and their outcomes that the decision-maker will be most likely to make the best choice. This task is frequently more difficult than engineers anticipate.

A decision involves both electing to behave in a certain way and committing oneself to follow through with this choice [2]. This paper will firstly review the ways in which decision analysis has evolved, within society in general and engineering specifically. It will argue that engineering training regimes inadequately equip engineers to communicate their findings to non-technical people. It is the thesis of this paper that cognitive psychology and decision-making philosophy are valuable skills which complement engineering rationality as it is these complementary skills that are fundamental prerequisites for the effective communication of the outcomes of engineering analyses to managers and clients. The paper concludes with a proposal that an understanding of human factors is a necessary skill for engineers wishing to influence decision-makers.

2. The Evolution of Engineering Decision Making

2.1. Historical Origins

2.1.1. Prudential Algebra

In the 1770s Benjamin Franklin had written of comparing options using 'moral or prudential algebra'. Joseph Priestley wrote to Franklin asking for advice. Franklin replied that he could not tell Priestley what to do, since he lacked sufficient contextual information, but was willing to advise *how* to make such decisions. The method involved writing in adjacent columns the 'for' and 'against' considerations, to facilitate simultaneous viewing and comparison. Each item was assessed and assigned weightings, which were then summed to arrive at a net positive or negative judgement.

Franklin's tool is now known as a T-chart, and is a predecessor of the SWOT (strengths, weaknesses, opportunities and threats) analysis. Such tools are utilised by organisations to identify the internal and external factors influencing a given decision.

2.1.2. Statistical Analytics

Statisticians played a key role in the Allied effort during World War II. The Statistical Research Group (SRG) applied statistical methods such as sequential analysis and sampling inspection [3]. In search of ways to minimise aircraft losses to enemy fire, the SRG examined distributions of damage observed on returning bombers. The most damage was found on the wings, with less on fuselage and tail. It was natural for bomber command to respond by reinforcing the wings, but Abraham Wald [4] disagreed. Wald pointed out that the inspection was necessarily limited to aircraft that had survived their missions, while those shot down were unavailable for assessment. Assuming that projectile strikes must be uniformly distributed, Wald argued that the observed distributions must be biased towards relatively benign locations which had not disabled the aeroplane. Consequently, it would be more relevant to reinforce those areas which, based on the evidence of non-return, must represent more catastrophic locations for damage. Wald's work was seminal in the then-fledgling discipline of operational research, and his theory became known as **survivor bias**.

In the 1950s such statistical analytical methods developed into **Decision Analysis**, which in its simplest form consists of formulating the problem, identifying possible options, and systematically assessing the possibilities [5].

2.1.3. Expected Utility

The converse concepts of 'expected utility' (combining desired events with probabilities) and 'mutual assured destruction' were seminal outputs from early research into decision analysis [6]. Developing what later became known as **Bayesian statistics**, they compared candidate methods of revising probabilities as new information becomes available. *The Foundations of Statistics* [7] similarly analysed changing one's predictions in light of new information. A product of Savage's research team was *Portfolio Selection* [8] which led to the 1990 Nobel Prize in Economics.

Raiffa and Schlaifer developed *Applied Statistical Decision Theory* [9] and *Decision Analysis* [10], arguing that standard regression methods were of limited use to business leaders, instead favouring a Bayesian approach. Their **decision tree** displays a set of alternative values for each decision and chance variable, arrayed as branches emanating from each node. This and *Decisions with Multiple Objectives* [11] laid the foundation of decision analysis as it is practiced today.

2.2. A Dichotomy of Approaches

In our earlier paper [12] we briefly reviewed the historical evolution of two opposing views regarding methods of decision-making. The developing views were described under the headings of decision analysis, behavioural economics, bounded rationality and ecological rationality. From this review emerged a picture of a dichotomy between how statisticians and other theorists typically recommend that decisions should be made, and the way in which decisions are more often made in practice.

The dichotomy has come to be expressed by the terms **System 1** versus **System 2**, or the more colloquial terms **hot and fast** versus **cold and slow**, both of which derive from the works of Kahneman and Tversky [13]. System 2 describes the ideal, rigorous approach recommended by statisticians for use by persons in authority making decisions of consequence. System 1 describes the more intuitive and visceral approach that the average person more typically uses for everyday decisions. According to the proponents of System 2, it is regrettable that managers often fail to employ well-researched objective methods and instead make decisions based on emotion or other unverified pathways.

Decision Analysis represents the cold-and-slow System 2. It is a mathematical approach which sits well with both engineers and economists, using computational models to combine expected utility and Bayesian statistics with engineering techniques. However, the dichotomy is not as simple as theory versus practice, nor even good practice versus bad practice. An increasing number of authors have argued that more streamlined approaches to decision-making, having at least some features in common with System 1, can not only be valid but in some circumstances may be superior to System 2. The key to understanding this possibility lies in the concept of **heuristics**.

Until relatively recently, the word 'heuristic' was primarily an adjective describing a method of learning and discovery that is experiential rather than prescriptive. Even within mathematics and science the term could be used to describe "*reasoning from past experience since no algorithm exists or is relevant*" [14]. The word has come to be used as a noun, most simply characterised as a pragmatic short-cut based on experience. Kahneman and Tversky [15] and Tversky and Kahneman [16] used it in this sense, observing that such approaches could sometimes lead to reasonably accurate predictions, but more often erroneous ones.

The obvious advantage of System 1 is that it can reach results more quickly, and in some circumstances this is imperative. While System 2 is usually more reliable, it has come to be acknowledged that sometimes a viable alternative is to use short-cuts or 'smart defaults' leading to a 'satisfactory', rather than best or optimal, solution [17, 18]. Building upon Simon's concept of **bounded rationality**, Gigerenzer [19] built a case for what he termed **ecological rationality**. Gigerenzer cited numerous circumstances in which System 1 can be more accurate than System 2 [20].

To further progress (or resolve) the debate between these two approaches, it is necessary to appreciate that there is a difference between 'heuristics' and 'bias'. Bias will be discussed later in this paper. Heuristics have come to be understood as smart defaults, often based on targeted training [21, 22]. The apparent intuition employed by highly skilled people such as fire-fighters, pilots and sports champions could be described as the subconscious making calculations that the conscious mind does not have time to articulate. Within the military, this is taught through rote memorisation and imitation, based on the four-step **OODA** loop (observe, orient, decide, act). The OODA method filters and contextualises available information, then facilitates arrival at a relatively rapid decision, yet acknowledges the possible need for future adjustments when more information becomes available.

2.3. Decision Analytics in the Modern Era

2.3.1. Risk-Based Decision-making

Industries such as oil and gas exploration and production and pharmaceuticals manufacturing are major users of risk-based decision-making [23]. As a process, risk-based decision-making organises information about one or more possible undesirable events into a broad, orderly structure that helps managers make informed choices. Sometimes overlooked in everyday management practice, risk-based decision-making commences with the following preliminary steps:

(a) Clearly defining the decision that must be made;
(b) Determining who needs to be involved in the decision;
(c) Identifying available options and the factors that will influence the decision-maker; and finally
(d) Collating all the information that will influence the stakeholders.

These steps must be completed prior to performing the risk assessments and applying the results.

As an example, safety regulations require the UK offshore community to develop comprehensive approaches to managing major hazards. Being legally bound to demonstrate the effectiveness of its risk management systems, the United Kingdom Offshore Operators Association developed the UKOOA SFARP Decision-Making Framework [24]. This development occurred within a socio-cultural atmosphere of low trust in large organisations, whereby both the workforce and the general public demand more information regarding issues affecting them. Corporate social responsibilities have evolved from 'tell me' through 'show me' to 'involve me', resulting in more transparent decision-making [25].

The focal point of the UKOOA framework is a chart illustrating a hierarchy of governing principles applicable across a three-tier categorisation of contexts [24]. Type A contexts are those for which a project initiative is well-supported by prior art. For these, the major factors influencing decisions are national and international standards, industry codes, and industry good practice. Type B involves some lifecycle uncertainty and deviation from the norm. Greater deviations require increasing application of engineering analysis and judgement combined with quantitative risk assessment (**QRA**). Type C projects are highly innovative and unique, requiring more formal exploration of both company ethos and societal values in regard to acceptable risks.

2.3.2. Data-driven Decision-making

In those cases where System 1 seems superior to System 2, the reason is often lack of time, lack of reliable data, or lack of data processing facilities. These limitations are increasingly able to be overcome through use of technology.

Data-driven decision-making (**DDDM**) requires that any proposed course of action be statistically validated before committing to it. Although congruent philosophies have existed in business for centuries, their full development was dependent on the computer revolution, with industry now generating more than 2.5 quintillion bytes of data each day [26].

DDDM's premise is that decisions should be founded upon analysis of key data sets, permitting quantitative prediction of efficacy and consequences. The core of data analytics is the recognition of statistically significant patterns and correlations, from which insights and conclusions can be drawn. Data visualisation products, such as Tableau and Microsoft's Power BI, enable the commercial sector to quickly interpret data into actionable insights.

Within engineering, the collection and analysis of data has long played an important role. The advancement of technology continually enhances the ease with which data can be collected and analysed. Moreover, data are objective, in a way that instinct and intuition are not, hence appropriate handling of data can assist by removing the subjective elements from decision-making. This increases the confidence with which decisions are made. Formal asset management programs rely upon evidence-based and data-driven decision-making processes. The accurate collection, organisation and retrievable storage of data and documentation are often required by statutory bodies, as well as being prerequisite to effective communication with stakeholders. Benchmarking, Mean Time Between Failure (**MTBF**), predictive maintenance, reliability data, maintenance scheduling and full Integrated Logistics Support (**ILS**) are various examples of how data analysis has contributed to confident decision-making. As the tools and usage of data analytics mature, there is a demonstrable increase in the value of insights drawn. The Gartner Analytic Ascendancy model [27] presents a four-stage model of the progressive maturation of data analytics, which demonstrates how the analysis can evolve and increase in value. Gartner's progression is from Descriptive (e.g., what is happening in our organisation), to Diagnostic (reasons why these things are occurring), to Predictive (what is likely to happen next), and finally to Prescriptive (actions we should take to achieve desirable outcomes). This represents an evolution from simple, passive, low value information to optimised, active value generators.

However, DDDM does not remove the human element of decision-making entirely. Being based on sound data does not guarantee that a decision will always be correct. The data set is the necessary resource to support sound decision-making, but there are numerous steps in the subsequent analysis and interpretation where errors can be made, leading to flawed decisions. For this reason, it is important to maintain a program of monitoring and assessing outcomes. This provides feedback and hence opportunities for refinement of practices.

2.4. The Science of Influence

2.4.1. Nudge Theory

Nudge Theory [28, 29] was briefly mentioned in our earlier paper [12]. The origins of the theory include two key observations of human behaviour, namely (a) that people find retrospective justifications for what they imagine are careful choices, and (b) people tend to be biased towards optimism and overconfidence. As a form of behavioural economics or indeed behavioural engineering, the approach is to tap into people's weaknesses in such a way as to encourage behaviours that are both socially and personally beneficial in the longer term. The work has received numerous favourable reviews, and the notion of **libertarian paternalism** is seen by many as striking a constructive balance in public policy.

A manifestation of tendency (b) is a lack of commitment to personal savings for retirement, even when there are tax incentives for such savings. This and other elements of nudge theory have been adopted by several governments in efforts to reduce the dependency of ageing populations on state-run welfare schemes. In 2010 the British Government established the Behavioural Insights Team (**BIT**), unofficially known within the UK as the 'Nudge Unit' and whimsically in the US as 'Britain's Ministry of Nudges'. By application of nudge theory, BIT helped push a raft of policies throughout parliament [30]. These policies have not been without controversy. Some have clear and direct personal and societal benefits, for example: using reciprocity to encourage people to join the organ donor register; encouraging charitable giving in wills; promoting installation of thermal insulation in homes to reduce energy usage; using a lottery to increase electoral participation rates. Others more directly aim to improve the government's balance of payments at the individual's expense, for example increasing fine payment rates through text messages, and benefit sanctions for disabled people.

2.4.2. Cognitive Engineering

Cognitive Engineering (**CE**) [31] is primarily concerned with human-machine interfaces, applied to fields as diverse as air traffic control and military combat [32]. Its application is familiar to many in relation the usability of sociotechnical systems such as computers and telecommunications interfaces. A relevant model is **GOMS** (goals, operators, methods, selection) [33]. The four elements of the acronym do not indicate steps to be undertaken in order. Instead, the Operators are the smallest divisible components within the critical path of an overall Method that is used to achieve the Goal. Selection rules are used to evaluate the relative merits of alternative possible methods. In most cases the aim is to find the Method which can accomplish the goal in the least time.

Another common application of CE is in the design, development and manufacturing of novel machines. Conventional design techniques include mechanical modelling, iterative design, usability testing and rapid prototyping, and manufacturing management has focused on physical layouts and time-and-motion studies. CE aims to go beyond these by applying cognitive psychology to evaluate behaviours, opinions, and perspectives.

There are challenges. A wide variety of social, cultural, political and economic considerations need to be addressed, and cognitive psychologists are not necessarily equipped to address them all [34]. Technology advances exponentially, but skills in using it and in anticipating potential hazardous side-effects take time to learn. Risks may be overlooked until a high-profile incident occurs, exposing the flaws. Anything created for people to use should be designed taking account of human capabilities, limitations, tendencies and preferences. Often, however, the challenge is convincing an existing culture of the value of the new ideas.

Commercial aviation provides an example of the effective application of cognitive engineering. After the crash of United Airlines flight 173 in 1979, Helmreich developed Crew Resource Management (**CRM**) [35]. CRM is a form of Advanced Team Decision Making (**ATDM**) [36], also known as Group Decision Making or Collaborative Decision Making. Adopted by United Airlines in 1981, the CRM program focused on factors affecting crew interactions. It acknowledged the differing perspectives of staff in different roles, seeking to deal with common phenomena such as over-assertive captains and passive junior officers. It challenged the prevailing culture in which the captain had total authority, and initially was not readily accepted by the pilots themselves or by some airlines. Nevertheless, CRM was adopted by the industry, and by 1985 CRM had become mandated by the Federal Aviation Authority. Further development and iteration led to the *Line Operations Safety Audit* (**LOSA**), adopted in 2005 by the UN's International Civil Aviation Organisation [34].

The aviation industry is strongly aware of the complexity of human cognitive behaviours during problem-solving and decision-making. With technological advances, flight deck decision-making can potentially be impaired by an over-reliance on automation. Automation increases the efficiency of situational awareness and workload management but is claimed to have inadvertently created a generation of pilots less skilled in risk-based decision-making [37]. The US National Transport Safety Board has corroborated [38] a report from Boeing [39] which concluded that, despite the advances in technology, there has been no reduction in the incidence of accidents attributable to pilot error.

A branch of CE called cognitive engineering and decision making (CEDM) has its own dedicated research journal [40]. CE and CEDM endeavour to penetrate to the centre of the decision space, in order to fully understand the decisions people make and how they can be supported in making them. Building on the understanding of bias, experts in cognitive engineering have developed markers which allow trained observers to distinguish skilled and effectual teammates from less skilled or dysfunctional ones. This **Recognition-Primed Decision** [41] is claimed to improve individuals' and teams' decision-making abilities in complex settings. It identifies characteristic behaviours, notably the recognition and subsequent correction of ambiguities and misunderstandings, which differentiate effective from ineffective teams.

2.4.3. Behavioural Engineering

Related to Cognitive Engineering, several groups have used the term Behavioural Engineering (**BE**) or Applied Behaviour Analysis. Like CE, BE aims to identify the causes of suboptimal performance of human-technology interfaces within wider systems. It endeavours to facilitate design practices which accommodate the strengths and limitations of human operators. Proponents emphasise the promotion of timely and accurate decision-making by comprehensively identifying and rationally applying all relevant contributing factors.

In terms of end goals, BE refers to the application of psychological sciences to management techniques for the maintenance or modification of human behaviour. In this sense it is congruent with nudge theory. BE has been successfully applied to organisational safety and performance, social services, prisons, social welfare and the space program. There was a journal dedicated to the subject, called *Behavioural Engineering*, published between 1973 and 1985.

3. The Psychology of Decision-Making

3.1. Unknowns

What happens when we make decisions without being aware that we are missing key information? Social science research has shown that, without realising it, decision-makers commonly ignore certain critical information [42]. This echoes the United States Secretary of Defence's famous statement, reproduced below [43]:

"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones."

Although Rumsfeld was lampooned at the time by popular media, twelve centuries previously in Medina in modern day Saudi Arabia, Imam Mālik ibn Anas wrote in his annals of Islamic History that "*Knowledge is knowing what you don't know*". At the time Rumsfeld was conducting his news briefing, NASA was already using the phrase 'unknown unknowns', and at Cornell University, psychology professor David Dunning was investigating the effect of unknown unknowns on decision-making.

Dunning had previously co-published a paper entitled *Unskilled and unaware of it: how difficulties of recognizing one's own incompetence lead to inflated self-assessments* [44], inspired by a bank robber who rubbed lemon juice on his face prior to committing his crime, believing it made him invisible. The whole crime was recorded on CCTV and the felon was amazed he was caught. The research for the paper involved testing participants on their logic, grammar and sense of humour, finding that those who performed in the bottom quartile rated their skills far above average. This led to the **Dunning-Kruger Effect**, that incompetent people lack the competence to recognise their incompetence. It illustrates that a little knowledge is a dangerous thing, because overconfidence in an area of limited expertise results in ill-advised conclusions and unwise choices, compounded by blindness to this.

However, lack of awareness of key areas of missing information can present difficulties even among those with genuinely advanced competencies and thorough knowledge.

Competent engineers should be aware of the boundary between the routine and the novel. While many spend their careers dealing primarily with application of well-established engineering methods, others are required to tackle problems requiring new approaches. Either from their own experience or by observing the attempts of others, the latter engineers are aware that it is difficult to assemble the resources necessary to solve such problems. Nevertheless, despite in-principal awareness of the difficulty, problems outside the range of previous experience may contain *unknowns* for which the engineer not only lacks the answer but may not even be aware of the relevant question [45].

A possible means of addressing this problem is to establish a framework of elicitation, using interviews, scenarios, prototypes, etc. By applying **Common Ground** discourse theory [46, 47], it is suggested [48] that the relative *known-ness* of project requirements can be categorised, and likely *unknown unknowns* sought and identified. If engineers can better define the *unknowns* of consequence, they will be in a better position to assess the spectrum of risks.

3.2.Bias

3.2.1. Cognitive Biases

The cognitive process of decision-making involves selecting from among multiple alternative choices. However, the original field of alternatives might be influenced by the decision-makers' prior views [2]. Factors that can limit one's ability to make optimal decisions include insufficient information and lack of adequate time or emotional resources.

The mental processes employed in forming opinions and selecting courses of action involve a combination of reason and bias. The American Psychological Association defines bias as a general pattern or tendency to think a certain way.

Some patterns of habitual thinking can provide people with useful mental shortcuts, developed and proven effective over years of experience. These permit decisions to made quickly and automatically. In this respect they are like heuristics, as discussed earlier. However, in contrast to heuristics, which can provide a valid approach to problem solving, most biases lead to error. They distort our perception of reality.

One form of bias is prejudice, such as stereotyping, which relates to *what* we think. Another form, relating to *how* we think, are **cognitive biases.** These are ingrained patterns of thinking that are poorly founded in evidence or logic, leading to inaccurate conclusions. Although far from exhaustive, Table 1, Annex A lists the principal cognitive biases that relate to engineering decision-making.

3.2.2. Blind Spots

The nucleus of an organisation is its people. Successful organisations require staff who are not only qualified and competent but who also possess personal qualities enabling them to work effectively as individuals and in groups [49]. To be effective, managers must focus on their own communication skills and on the welfare of their staff [50]. Mutual understanding is a defining characteristic for effective and open communication and good interpersonal relationships. These characteristics demonstrably enhance individual performance and improve organisational productivity [49].

The Johari Window (Figure 1) developed by Luft and Ingham [51] provides insight for self-awareness and understanding, leading to improved interpersonal communication. A useful feature of the model is that it acknowledges the existence of blind spots, which are examples of *unknown unknowns*. This communication model has the potential to enhance emotional intelligence (EQ), which in turn facilitates an environment of creativity and collaborative learning.

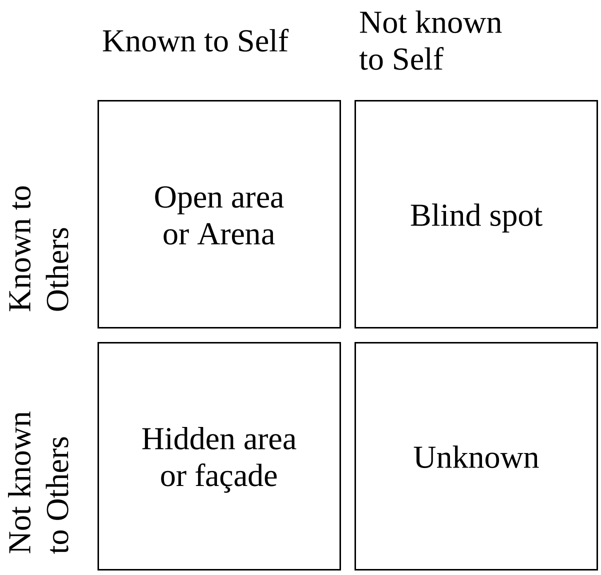

Figure 1: The Johari Window model

3.2.3. Authority Bias

Sometimes, seemingly illogical choices overtake rational decision-making. When evaluated in hindsight and with more information, decisions made in extreme situations can seem irrational, harmful, or even vicious. Beginning in 1960, Milgram [51] conducted a series of experiments on human subjects which became one of the most famous (or notorious) psychology studies. The findings revealed the potential conflict between personal conscience and obedience to authority. Many of those accused at the World War II Nuremberg trials justified their actions on the grounds that they were following orders from their superiors. Evidently, ordinary people are inclined follow instructions from an authority figure, even to the extent of killing an innocent person.

Obedience to authority is ingrained in our psyche. Based on our upbringing, education, and workplace experiences, we tend to comply with instructions from those whose authority we regard as legally or morally legitimate [53].

Building on research into career choices [54], Athanasiou [55] characterised the engineering training continuum as authoritarian in nature. This is reinforced in the commercial setting where there is a defined hierarchical structure. To be considered for promotion to senior engineering positions, such as Chief Engineer within an Authorised Engineering Organisation, engineers are required to obtain design authority or engineering authority. This usually carries the pre-requisite of having gained Chartered Professional status through an accredited institution or professional governing body, such as Engineers Australia. For example, the Board of Professional Engineers Queensland and the Professional Engineers Act 2002 stipulate that any professional engineering services in or for the state of Queensland must be performed by a Registered Professional Engineer Queensland (**RPEQ**). Products, infrastructure, and services used by the public must be designed, built and maintained by appropriately qualified, competent, experienced and *registered* engineers. The only exceptions are services carried out under a prescriptive standard or under the direct supervision of an RPEQ who takes full professional responsibility for the work.

Although vitally important to ensure the standard and integrity of engineering decision-making, this structure might make engineers susceptible to authority bias. Instead of defining the desired outcome and letting the creative mind find an innovative path, engineering practice tends to prescribe what steps should be taken.

These are commonly viewed as separate skills, competing for the available training time and hence effectively at odds with the technical skills required to be an engineer. Engineering practice tends to be built on a conservative approach that does not readily deviate from known solutions. It relies on a Best Practice approach which can sometimes stifle creative thinking. It may take considerable drive and/or expert mentoring for someone to move beyond reliance on memorisation and imitation in order to become truly innovative. Despite the encouragement of broad-based competency documents such as cited above [56], it couldbe argued that few engineering schools or disciplines actively (or successfully) encourage such behaviour.

3.3.Rationality, Reason and Persuasion

3.3.1. Reason versus Rationality

The words ‘rationality’ and ‘reason’ both have a spectrum of meanings, sometimes overlapping and sometimes conflicting, which can be difficult to deconvolute. In philosophy, psychology and the sciences generally, the words rationality and reason are commonly used as synonyms, both relating to the ability and discipline of using and adhering to rigorous logic. Synonyms include objective, logical, coherent and intellectual, while common antonyms include subjective, irrational, illogical and emotional.

It is generally (though not universally) agreed that a rational person is one whose thoughts and actions are ruled by reason more so than by emotion. But in the context of this paper, it is important to appreciate that these words and their related forms are sometimes used in almost diametrically opposed senses. For example, the words ‘rationalise’, and ‘rationalisation’ are often used to denote an after-the-fact justification or excuse for a person’s irrational or immoral behaviour. Similarly, a common meaning of the word ‘reason’ is a justification or claimed cause of an action or event, or part of an argument in favour of a proposal, where sometimes the claimed reasons have minimal basis in fact. Counterfactual thinking is a concept in psychology describing the human tendency to create alternative versions of past events that are contrary to what actually happened [57].

All of these varied meanings have relevance to the topic of this paper. The primary meanings listed above can be considered in some sense noble, whereas the latter meanings less so. Nevertheless, both ends of the spectrum of meanings are relevant to an engineer presenting the results of an analysis to a manager, client or other decision-maker. The engineer has performed the analysis based on ‘hard’ data and rigorous logic, but then hopes that the decision-maker will be *persuaded* by these results to take a particular action. A key question is whether the technical results, of themselves, have sufficient persuasive power to achieve the desired goal. This requires attention to a secondary but relevant meaning of the word ‘reasoning’.

3.3.2. Persuasion

Tolstoy wrote “*The most difficult subjects can be explained to the most slow-witted man if he has not formed any idea of them already; but the simplest thing cannot be made clear to the most intelligent man if he is firmly persuaded that he knows already*.” [58, 59]

Mercier and Sperber [60] maintain that reasoning is, first and foremost, a social competence. They argue that the main function of reasoning is not so much to enable us to solve problems or analyse complex data (which is the function of rationality), but rather to navigate the challenges of living in collaborative groups. In this sense the function of reason is to produce and evaluate the 'reasons' why a person should decide and act in a certain way. Reasoning is concerned not only with the question of whether or not something is the case, but also with *why* we should believe it to be so. This is epistemology.

Such reasoning can be considered in terms of 'evidence', but evidence operates at different levels depending on the audience. For scientists it is tested by the process of peer review, meaning scrutiny by well-informed, sceptical colleagues. For example: Freud's 'Psychological Wednesday Society' helped him advance his ideas of psychoanalysis; Isaac Newton's work on alchemy was deemed inferior to his astronomy, because in the latter he was able to convince a community of peers. Not only does the peer review process validate the integrity and reliability of the work, thus ensuring 'good science', but it also evaluates the standards of *presentation* of the work and its results. The latter is important for the scientific or engineering community, but it becomes even more important when the intended audience members are not scientists or engineers.

Thus, the matter at hand becomes one of not only *rationality* (to arrive at reliable results), but also one of providing the *reasons* why a decision-maker should be convinced by these results and should act accordingly. In this sense, *reason* is akin to argument or persuasion. How, then, does one reason or argue successfully? There could be a spectrum of possible approaches:

(A) Self-consistent lies: Joseph Goebbels, Hitler's Propaganda Minister in Nazi Germany, is reported to have said, "*If you repeat a lie often enough, people will believe it, and you will even come to believe it yourself.*"

(B) Simplistic, edited truth delivered with great confidence: Advertisers and politicians are constrained to adhere at least somewhat to truthful presentation of facts, otherwise risking censure and legal action. However, both groups commonly use tactics involving simplification of facts and selective omission of inconvenient details. In common with (A), they often employ a combination of strident assertions and frequent repetition, aiming to give the audience no opportunity to object or even to think about contrary views.

(C) Exploit weaknesses and biases: Lacking skills, time or diligence, people do not routinely apply critical thinking when forming judgements. Instead, their choices are directed by a variety of biases (see Annexe A). If a person's bias can be anticipated, it might be possible to use it to influencethem.

(D) Anticipate the audience's legitimate needs: In *Topics from Organon*, Aristotle proposed that to argue convincingly for a given position, one must be proficient at critical thinking and seeing the different sides of a question, including counterarguments. But in addition to being skilled in objective reasoning, this also requires one to be attuned to the audience (a manifestation of emotional intelligence).

(E) Overwhelming facts and detail: The personalities of many engineers are such that they believe that the facts alone, so long as presented rigorously and supported by enough equations, data tables and graphs, should be persuasive. Experience suggests that such engineers can bemistaken.

It is the thesis of this paper that option (D) should be the engineer's aim. Option (E) is only occasionally successful, being too dependent on the recipient's knowledge level. Options (A) and (B) are unacceptable, being incompatible with the Engineer's Code of Ethics. Option (D) may share some points in common with option (C), in the sense that it is important to be sufficiently aware of likely biases that these biases can be counter-balanced with appropriate reasoned argument supported by statistically valid facts.

The need for such anticipation is not restricted to situations that are politically charged or especially polarised (although decisions involving large sums of money are often both). But the literature from cognitive psychology indicates that the more convincing proponents of a recommended course of action are those who can anticipate likely responses and tailor their presentation to the audience's legitimate needs [61].

3.3.3. Anticipation and Epistemic Vigilance

'*Forewarned is forearmed*', goes the proverb. The ability to anticipate recipients' reactions can strongly affect an engineer's success in persuasion.

Although (like any human) a decision-maker can be prone to weaknesses and biases, overall a person requires an above-average set of reasoning skills to rise to a position of authority. Decision-makers are accutely aware that various people will attempt to influence their decisions, and they develop defences against such influence. When presented with a set of reasons purporting to justify a proposed course of action, they have at least some ability to examine the proffered reasons and judge their validity. Epistemology is the philosophical theory of knowledge, especially when applied to critiquing the justification for believing something to be true. Accordingly, high-level decision-makers exercise quality evaluation of the reasoning based on the trustworthiness and credibility of the source, known as *epistemic vigilance*, when receiving information from others, to avoid being misled [62]. This includes a degree of scepticism regarding presented statistics and other forms of scientific evidence — which, from experience, they are aware can be misrepresented [63].

We contend that the difference between a good engineer and a commercially successful one is the ability to communicate effectively. This is not to denigrate rationality. The engineer's traditional rationality is important, both to arrive at the correct answer in the first place and then to assemble the data in a professional and convincing manner. Although not sufficient in isolation, they are necessary, if the decision-maker is astute and diligent. Moreover, the ability to mount a convincing case derives partly from empathy and partly from one's own ability to exercise epistemic vigilance. Another contributory factor can be *consequential reasoning*, manifesting as the ability to anticipate recipients' reactions and should include the ability to identify likely biases and possible counterfactual thinking. This is different from *consequentialism*, which is an ethical theory that judges whether something is right by its consequences.

3.3.4. Skills Acquisition

How does one acquire the skills of reasoning and persuasion? Dutilh Novaes [61] postulates that reasoning is tuned by social interaction, being an adaption geared towards highly cooperative social structures. In support of this view, she compares the biologically evolved trait of spoken language with the culturally evolved trait of written languages. Spoken language is argued to be evolutionary on the grounds that every known human population has such a communication system, which emerges in individuals merely by exposure. By contrast written languages are exclusively products of advanced societies, and their acquisition by an individual requires formal instruction over an extended period. Dutilh Novaes submits that the cognitive skill of reasoning is more akin to written language than to spoken, because sociocultural environments have driven the evolution of reasoning skills.

It is instructive to expand on some examples, but also consider possible contrary factors.

- Humans demonstrate a powerful tendency to cooperate and coordinate for action. They do this in ways vastly more complex and farther-reaching than the coordination displayed by, for example, hunting teams of wolves or dolphins.

- Humans engage in complex linguistic communications, on abstract as well as concrete topics.

- Humans have an ability to understand and vicariously experience others' perspectives. *Caveats*: Animals such as dogs clearly also display empathy, or perhaps sympathy, at an emotional level; Humans' capacity to appreciate the views of others is often decidedly limited, as discussed here under the topic of Bias.

- The instinct to construct causal connections between observed phenomena. Such causality is inherent in the ability to accept a given collection of data as a reason to accept a proposition.

Dutilh Novaes concludes that reasoning is a product of sociocultural environments, evolving by means of feedback loops between genetic and cultural processes.

Despite this capacity for independent reasoning, humans are also susceptible to the tendency to follow the crowd. It is observed that the probability of a person adopting a belief increases as a function of the number of others around them who already hold that belief. This is known as Group Think or Herd Behaviour, the latter referring to the corresponding animal behaviour and likely to have evolutionary origins. Harvard psychologist Steven Pinker is quoted [59] as saying "*People are embraced or condemned according to their beliefs, so one function of the mind may be to hold beliefs that bring the belief-holder the greatest number of allies, protectors, or disciples, rather than beliefs that are most likely to be true*". People are forced to balance their sometimes-conflicting desires to embrace truth and to remain part of a tribe.

4. Discussion

4.1. Engineering Curricula

As stated above, the difference between a good engineer and a successful one is the ability to convincingly communicate rational thought and consequential reasoning to non-technical senior management. Such interpersonal communication skills are essential for an early-career engineer to develop into a leader [64]. Engineering education has traditionally focused on technical content and skills, with little consideration to how the learning environment can be used to foster broader and more communicative thinking styles. Those who typically choose an engineering career are the types of people who feel most comfortable with questions that have a single correct answer (although this description applies to most people [65]). Experiential or problem-based learning may occur, but the focus is usually on technical outcomes rather than human factors.

The types of problems engineering graduates need to be able to address involve complex interactions of technology, systems, and society [66]. In Trevelyan's [67] opinion, key aspects of what is required to become an expert engineer are not taught in most engineering schools. University engineering degree programs aim to provide students with the knowledge and skills they need to address technical challenges in the real world. Sola et al. [68] state that key elements of this ability are critical thinking and creativity, but their study finds evidence that these attributes are not being successfully taught. They engaged groups of first year and final year students to undertake tests designed to assess both critical thinking and creativity. The results were discouraging, finding statistically significant differences which indicated a *decline* in creativity over the years of the engineering degree. Regarding critical thinking, the study confirmed previous literature indicating *no improvement*, but also showed engineering students to be inferior to other majors. Tekmen-Araci and Kuys [69] found that creativity is actively discouraged by excessive focus on product functionality during the engineering design process. There appears to be a need for a more cohesive approach to development of critical thinking skills in engineering programmes, including links and progression across modules and stages. An attribute valued by employers is the ability to solve both technical and interpersonal problems in the workplace [70]. It is therefore important to an engineer's career success to possess the insights required to recognise and apply both technical and emotional intelligence. In 1996 the Institution of Engineers Australia issued the report *Changing the Culture* [71], which recommended changes to the way engineers are educated. These recommendations were developed into a set of graduate attributes [72], subsequently promulgated to Australian universities. This is now presented as the Stage 1 Competency Standard for Professional Engineers [56]. As examples of its content, consider the following extracts, dealing with such matters as (i) complexity and the borders of knowledge and (ii) psycho-social awareness:

- Element 2.1(c): "*Competently addresses complex engineering problems which involve uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors*"

- Element 3.2(a): "*Is proficient in listening … including: comprehending critically and fairly the viewpoints of others*"

- "*expressing information effectively … engaging in discussion, presenting arguments and justification … to technical and non-technical audiences and using … media best suited to the context*"

- "*representing an engineering position … to the broader community*"

- "*appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences.*"

Several universities now offer courses aimed to 'round out' an engineer's education, such as the *Masters in Engineering Management* provided by, amongst others, Arkansas State and Ohio University. The University of Toronto's Faculty of Engineering offers certificate courses on engineering communication which emphasise the multidisciplinary nature of engineering practice. Since a given project may require collaboration with a wide variety of other professions, effective communication of complex concepts to non-engineers becomes critical. Recognising that both cognitive and cultural biases can affect engineering problem-solving, Stanford University and RWTH Aachen University have an international exchange program titled *Expanding Engineering Limits* [73]. They report evidence of effectiveness to improve students' appreciation for the importance of cultural diversity in the practice of their profession. Engineers perceive themselves as agents of change who can shape the future through technology. Most engineering students consider that their profession will have a net benefit to society [74]. However, such vision only comes to fruition if others adopt the technology [67]. This requires a series of people to be convinced of the value of the new idea and willing to change from established practices. This includes the end-users of the technology, those who market the innovation, and technicians who can translate ideas into reality, but most especially it depends on the decision-makers who will approve the finance [67].

The news is not all bad. Using statistical analysis of responses to a standardised questionnaire (business-focussed inventory of personality, BIP), Redomero et al [75] found that engineering students had reasonable proficiency in at least some 'soft skills'. To the authors' surprise, they found that engineering students performed better than education students at coherent expression of opinions and ideas, and at active listening.

However, the literature indicates that engineering education remains overwhelmingly focussed on design and technical problem-solving, reflecting the priorities applicable in the 1950s. But even in the 1950s, the *Report on Evaluation of Engineering Education* recommended that approximately 20% of the curriculum should be devoted to "*humanistic and social studies (pages 39-41)*" [76]. According to Trevelyan [67], this recommendation has been almost completely ignored. If so, such neglect fails to prepare engineers for careers in which they must interact extensively with other people.

Engineers must learn how to communicate scientific findings, and debunk false claims, in ways that resonate better with the general public, managers and policymakers. The rise of 'populism' in politics coincides with adoption of anti-science ideologies and declining trust in traditional sources of authority [65]. These movements are epitomised by their use of the phrase 'so-called experts'. If engineers aspire to be perceived as *genuine* experts capable of winning the trust of a sceptical society, they will need more than technical expertise. They must display a broader-based wisdom, a holistic comprehension of human nature and of the human consequences of their work outputs. This starts with an education containing both formal and informal training in the skills of communication — including the presentation of conjugated argument, scientific facts and demonstratable outcomes, but also the honest yet authoritative presentation of uncertainty and risk.

4.2. Unaware and Overconfident

In the information age, rationality as an applied skill appears to be declining. This manifests as the **illusion of explanatory depth** whereby people believe they have greater knowledge than they actually possess [77]. Like the Dunning-Kruger Effect, this reinforces the work of Mercier

& Sperber [60] and Dutilh Novaes [61]. Sloman & Fernbach propose that the exponential growth of information availability has diminished the evolutionary development of reasoning and rationality. The illusion of explanatory depth results in people holding strong opinions not derived from deep understanding.

Kolbert [78] reviews the findings of a 1975 psychology experiment which demonstrated the remarkable persistence of opinions once formed, even after the original information leading to the opinion was revealed to have been fictitious. This is termed Anchoring Bias. The challenge for the scientific community is to close the gap between factual reasoning and popular bias-based opinions. At a time when society is grappling with 'alternative facts' and 'fake news', scientists and engineers need an ability to address the tendencies that lead to false beliefs about technology [65].

Amazon founder Jeff Bezos has been repeatedly quoted [79, 80] as defining intelligent people as those who are open to reconsidering and changing their opinions when presented with new information. Changing a person's mind, however, is difficult. Influencing public perceptions and policy requires more than technical knowledge, a relevant message and the ability to communicate with colleagues. It requires an understanding of both audience and venue, and the ability to communicate effectively on many levels. Development of such skills requires strategic planning, targeted training, persistence, and a high tolerance for failure.

4.3. Us and Them

"My job involves explaining things to idiots, who make decisions based on misinterpreting what I said. Then it is my job to fix the massive problems caused by the bad decisions." 'Dilbert' [81].

Bias is not the sole province of non-technical people. Engineers need to appreciate that they are subject to their own set of biases. There are two opposing potential explanations for the identified need for engineers to attend specialist communication courses: it might be due to senior management imagining they have better understanding of technical matters than they really possess; or it might be a result of engineers having exaggerated cynicism regarding the intelligence, conflicting priorities and external influences affecting decision-makers. It is imperative to avoid an 'us and them' culture. Staff in technical departments of corporations may feel belittled as mere facilitators rather than core business functionaries. However, if these frustrations manifest as arrogance and combativeness, such behaviour is maladaptive.

As per the Dunning-Kruger Effect, unskilled people may be unaware and overconfident [82], lacking the skills to make rational decisions but also lacking the metacognitive ability to appreciate that their judgements are flawed. However, the attitudes of genuinely skilled people can also be subject to miscalibration. Sometimes experts officiously dismiss the potential value of contributions from experienced non-experts [44]. It behoves us to remember Plato, who quoted Socrates as 'knowing that he knew nothing' [83], and Kahneman's observation [13] that we are blind to our blindness.

Clear [59] states that opinions, even radical ones, are readily adopted if proposed by our friends, but dismissed as irrational if proposed by people different from ourselves. He suggests that tribalism and hostility are caused more by distance than by difference. Citing authorities as diverse as Abraham Lincoln and Alain de Botton, Clear [59] suggests that the solution is to get to know and appreciate people as individuals. These insights should help us to break down our own prejudices. Consistent with the Johari Window, if we can reduce the scope of our own blindness, we will become better communicators.

A helpful perspective may be re-branding of the term ‘soft skills’ as ‘entrepreneurial skills’ [84]. The latter term is likely to be more attractive to young engineers, yet equally or more effective in helping the requisite skills to be acquired.

4.4. Peer Review

Prince & Rogers [85] state that a thought leader is a person or company that is recognised by clients, intermediaries and even competitors as one of the foremost authorities in an area of specialisation. By speaking at industry events and publishing in a variety of journals, engineers can become known, familiar and trusted. This significantly increases the probability that their ideas will be validated and that they will be accepted as thought leaders. But these benefits are contingent upon the uncomfortable and sometimes humbling experience of submitting our work to the scrutiny of peers.

We must also recognise the potential for bias when it is our turn to act as referee. Kolbert [78] writes “*One way to look at science is as a system that corrects for people’s natural inclinations. In a well-run laboratory, there’s no room for myside bias; the results have to be reproducible in other laboratories, by researchers who have no motive to confirm them.*” But if peer review is critical to the advancement of the sciences, then confirmation bias and myside bias (see Annexe A) are its Achilles’ heel. As a scrutineer, such biases can colour the evaluation of hypotheses in favour of prior opinions and lead to the dismissal of evidence based on preconceptions. A diligent editor-in-chief should be on guard against the possibility of biased referees.

The above discussion on Authority Bias suggests that engineers can be susceptible to this weakness. Engineers operate in a quality-controlled system, requiring strict adherence to policies and procedures. This can exacerbate a personality or culture which is uncomfortable with uncertainty and defaults to a binary, Boolean view of true-or-false [86]. In Kahneman and Tversky’s nomenclature, general society operates by System 1 but engineers have an obligation to use System 2.

4.5. Shared Humanity

It is the professional world where most serious decision-making is performed, but both engineers and managers remain human. According to António Damásio, “*We are not thinking machines that feel; rather, we are feeling machines that think*” (87). To navigate the tension between living in System 1 but working in System 2, a key factor is to acknowledge both our own humanity and that of our audience. This will better equip us to communicate the persuasive power of the rational decision-making process.

Finally, the solution to perceived bias and counter-factual thinking is *not* for the engineer to tell the decision-maker to stop being emotional. Ultimately, emotion is what drives ethical and altruistic behaviour, since it derives from empathy [65]. Rather, the goal is for engineers to learn effective ways to convince managers that following the scientific evidence is the best way to advance their own interests and those their shareholders.

5. Conclusions

"When the winds of change blow, some people build walls, others build windmills."
Chinese Proverb

This paper explores the way in which engineering decision analysis has evolved in parallel with corresponding processes in society more generally. It highlights a dichotomy between rigorous but slow statistically based analytical methodologies (System 2) and intuitive or heuristic processes which may be more expedient (System 1). Examples are cited demonstrating that, when derived from expert training, heuristics can sometimes be more appropriate, even more reliable, than the long-hand approach.

In the great majority of cases the engineer's contribution is and should be grounded in System 2, using rigorous analysis of validated data. The work must be evidence-based and capable of withstanding scrutiny by other experts. However, in order to maximise the probability of their recommendations being accepted and implemented by managers and clients, engineers need to take account of human factors. Key considerations include the following:

- Human communication: The decision-maker is not a machine, programmed to accept data and deliver a deterministic output. For effective communication and appropriate response, the methods and results of the engineering analysis must be presented in a form intelligible by a non-technical person, or in a manner tailored to the recipient's field of expertise.

- Consequential reasoning: The presentation of results and recommendations should include consideration of the likely consequences to the various stakeholders, including society at large. The risks associated with various alternative pathways should be impartially assessed. Such consequential thinking is a major aspect of engineering codes of ethics and competency standards, but it is also critical to the persuasive power of the analytical findings.

- Anticipation of bias: Like anyone, managers can be subject to a variety of cognitive biases. To maximise their effectiveness in promoting sound decision-making, engineers should become proficient in anticipating common types of bias. Forewarned in this way, they may be able to present their findings in ways most likely to elicit a rational response rather than a prejudicial one. Engineers must also guard against their own susceptibilities to bias, avoiding arrogance, cynicism and combativeness.

- Reputation: To a significant extent, the probability of an engineer's recommendations being accepted is proportional to the engineer's reputation for reliability, authority and good sense. Such reputation is developed not only by performing sound analyses but also by making the effort to communicate their outputs to a wide audience, through pathways including the discipline of peer review.

The engineering community needs to recognise that engineering culture is alien to the way in which general society thinks and makes decisions. The mathematical mindset of an engineer elicits no resonance from the average person. Successful engineers are those who are proficient in translating between the language of their technical discipline and the language of the society around them. Moreover, they need to develop skills in explaining not only the results of the analysis but also the 'reasons' why they should be believed — the checks-and-balances which have been employed to ensure that the results are reliable.

The imperatives of technical content in the curriculum of an engineering degree program leave almost no room for study in the humanities. Yet most of an engineer's career involves dealing with humans, and career success depends on skill in such dealings. Developing engineers need structured learning in communication and socio-cultural emotional intelligence. Exposure to cognitive psychology and epistemology, especially in relation to the recognition of bias and false logic, would be beneficial. If formal courses in such subjects cannot be accommodated in the undergraduate degree, then at least their importance can be mentioned in the context of selected technical courses. Post-graduate certificate and/or continuing professional development opportunities could then be offered to aspiring professionals aware of their need for such competencies, in the same way as they undertake training in finance or business. Only when equipped with such human-oriented proficiencies will engineers fulfil their aspirations to "turn dreams into reality" [88].

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7. Annex A

Table 1: List of Cognitive Biases

BIAS	DESCRIPTION	EXAMPLES / CONSEQUENCES
Anchoring Bias	The human tendency to be over-reliant on the first piece of information heard or recalled.	Particularly prevalent in diagnostics, the analyst's first impressions of the case often create an anchoring point, which can sometimes incorrectly influence all subsequent diagnostic assessments due to a vital piece of information being overlooked. (89, 90)
Authority Bias	The tendency of people in a hierarchical system to make decisions based on what their leaders say, or what they guess their leader would think, even if they believe the leader to be wrong.	Often referred to as Sunflower Bias due to the fact that a person will go along with what the boss says, rather than having confidence in their own knowledge and experience, because they feel their leader 'must know better'. (91)
Availability Bias	People overestimate the importance of information that happens to be available to them, reverting to immediate examples that come to mind when evaluating a specific topic, concept, method or decision.	An untruth repeated often enough is eventually perceived as a truth. People tend to heavily weigh their judgments toward more recent information, making new opinions biased toward the latest news. (90)
Backfire Effect	The Backfire Effect causes people who encounter evidence which challenges their beliefs to reject that evidence, and to strengthen their support of their original stance.	A subtype of Confirmation Bias. When a person encounters information suggesting that their current beliefs are wrong in some way, they feel threatened, generating a variety of negative emotions. This is especially likely when the beliefs in question are crucial to the person's self-concept, hence representing an important part of their identity and ideology. (92)
Bandwidth Effect	'Bandwidth' describes the brain's capacity to perform functions that underlie higher-order behaviour and decision-making. When bandwidth is taxed, less is available for use in other judgements or decisions, leading to potentially undesirable choices	The brain operates on a two-system model: System 1 is the intuitive, automatic and effortless portion, which is prone to biases and errors; System 2 can produce accurate and unbiased results but is slower, more deliberate and effortful. Decreased bandwidth reduces the probability that a person can use their System 2 processes when making decisions, hence reverting to the less reliable System 1. (90,93)

Belief Bias	If a conclusion supports one's existing beliefs, anything that supports it will be rationalised.	This can happen when an observer assumes ahead of time that they know what the results of an experiment will be and as a consequence of that belief distorts the observations. (94)
Blind Spot Bias	Failing to recognise one's own cognitive biases.	Cognitive or motivational biases are much more readily recognised in others than in oneself. (90)
Bounded Awareness	Cognitive blinders prevent a person from seeing, seeking, using, or sharing highly relevant, easily accessible, and readily perceivable information during the decision-making process.	Most decision-makers are not aware of the specific ways in which their awareness is limited, nor of the consequences of this failure to recognise those limitations. Bounded awareness can occur at various points in the decision-making process: 1. Decision-makers fail to see or seek out key information needed to make a sound decision; 2. They fail to use the information that they do see because they aren't aware of its relevance; or 3. They fail to share information with others, thereby bounding the organisation's awareness. (89, 95)
Bounded Rationality	Decision makers seldom have the time or mental processing power to follow the optimisation process outlined by decision analysts, so they suffice with shortcuts and accept the first satisfactory course of action rather than continuing to search for the best.	Choosing a restaurant when hungry compared to choosing a restaurant for an upcoming major social event. (89)
Certainty Effect	When people overweight outcomes that are considered certain relative to outcomes that are merely possible.	People prefer a 100% discount on a cup of coffee every 10 days to other more frequent but lower discount offer, even though the second option may save them more money in the long run. (96)
Champion Bias	The tendency to evaluate a plan or proposal based on the track record of the person presenting it, more than on the facts supporting it.	Instrumental in the power of social media 'influencers'. (95)
Choice Overload	A cognitive process in which people have difficulty making a decision when faced with many options.	Too many choices might cause people to delay making decisions or avoid making them altogether. (90)

Confirmation Bias	The tendency to search for, interpret or listen only to information that confirms one's preconceptions, leading to statistical errors.	When people would like a certain idea to be true, they end up believing it to be true. They are motivated by wishful thinking. (89, 90, 92)
Curse of Knowledge Bias	Once you understand something, you presume it to be obvious to everyone.	Similar to Hindsight Bias, this can explain why communication games such as Charades or Pictionary may end in a stalemate between communicator and guesser. To the communicator it is obvious to what they are miming or drawing, but less obvious to the guesser. (92)
Decision Fatigue	After a long session of decision-making or repetitive decision-making tasks, people's mental resources are drained, therefore they tend to take the easiest choice (e.g., maintaining the status quo), resulting in a lower quality of decisions being made.	Researchers studied parole decisions made by experienced judges and found that the chances of a prisoner being granted parole depended on the time of the day that judges heard the case. 65% of cases were granted parole in the morning and fell dramatically with accumulating hours of a session. The rate returned to 65% after a lunch break, then fell again. (94)
Declinism	Declinism is remembering the past as better than it was and expecting the future to be worse than it is likely to be. Socrates is reported to exclaim that the written word would be the downfall of information dissemination, and more recently the same has been said about the internet.	When things change, so must the way in which we think about them; and because we are cognitively lazy (Kahneman, 2011; Simon, 1957), we try our best to avoid changing our thought processes. (92)
Dunning-Kruger Effect	People who are ignorant or unskilled in a given domain tend to believe they are more competent than they are. They therefore lack the competence to recognise their incompetence.	A nationwide survey found that 21% of Americans believed that it was 'very likely' that they would become millionaires within the next 10 years. (92)
Experience Bias	We take our perception to be the objective truth.	We assume our view of a given problem or situation constitutes the whole truth. (94)
Framing Effect	Being unduly influenced by context and delivery, people react to a choice in different ways depending on how it is presented i.e., as a loss or as a gain.	People tend to avoid risk when a positive frame is presented but seek risks when a negative frame is presented. For example, people are more likely to enjoy meat labelled 75% lean meat as opposed to 25% fat. (96)

Fundamental Attribution Error	Tendency to over-emphasise dispositional or personality-based explanations for behaviours observed in others, while discounting situational explanations.	Particularly relevant to forensic investigations, because investigators have a cognitive bias to assume that a person's actions depend on what 'kind' of person they are rather than on the social and environmental forces that might influence them. (89)
Group Think / Herd Behaviour	The tendency to go with the crowd, explaining the probability of one person adopting a belief increasing with the number of people who hold that belief.	Allowing the social dynamics of a group situation override objective evidence or probable best outcomes. When it turns negative, it can be a "mob mentality." (89)
Hindsight Bias	The tendency of people to overestimate their ability to have predicted an outcome that could not possibly have been predicted. Can result in oversimplification of cause-and-effect.	After the global financial crisis of 2007, many analysts stated that all the signs of the financial bubble had been plain to see. (92)
Loss-aversion Bias	People are more likely to select an option that is measured in units of success rather than failure, as the pain of losing is psychologically about twice as powerful as the pleasure of gaining.	Often observed in medical situations when the chance of success is presented as a survival rate rather than as a mortality rate. Linked to Ratio Bias. (89)
Myside Bias	When people evaluate evidence, generate evidence, and test hypotheses in a manner biased toward their own prior opinions and attitudes.	Similar to Confirmation Bias. The biases are most prevalent with emotionally significant issues and for established beliefs. For example, in reading about gun control or abortion, people usually prefer sources that affirm their existing attitudes. They also tend to interpret ambiguous evidence as supporting their existing position. (90, 95)
Negativity Bias	Allowing negative things to disproportionately influence one's thinking.	The pain of loss and hurt are felt more keenly and persistently than the fleeting gratification of pleasant things. (92)
Optimism / Pessimism Bias	One overestimates the likelihood of positive or negative outcomes.	Pessimism bias could make someone believe that they will fail an examination, even though they are well-prepared and likely to succeed. Vice versa for optimism bias. (92)

Projection Bias	The tendency of people to overestimate the degree to which other people agree with them. People tend to assume that others think, feel and believe much like they do. Also influences our estimations of our future selves.	Shopping when hungry results in tendency to buy unhealthy foods one does not normally eat, and larger quantities than normal. This not only increases costs but results in storage of unwanted goods. At the time of shopping, we incorrectly anticipate that our future hunger will be as great as at present. (92)
Ratio Bias	People’s difficulties in dealing with proportions or ratios as opposed to absolute numbers.	In a study, participants rated cancer as riskier when it was described as killing 1,286 out of 10,000 people than when described as killing 24.1% pf people, despite the fact that the latter is actually a much higher risk. The finding demonstrates that ratio bias can strongly influence perception of risk. In a similar study, participants rated the statement “36,500 people die from cancer every year” as representing higher risk than the statement “100 people die from cancer every day”. (89)
Representativeness Bias	People tend to judge the probability of an event by finding a ‘comparable known’ event and assuming that the probabilities will be similar.	When people rely on representativeness to make judgments, they are likely to judge wrongly, as the fact that something is more representative does not actually make it more likely. (89, 96)
Self-Serving Bias	The belief that our failures are due to external factors.	We attribute successes and positive outcomes to our own merits and initiative, but attribute failure and negative outcomes to other people or contextual factors outside ourselves. (92)
Status Quo Bias	A subconscious preference for continuing with the way things are, rather than initiating change, even when there is evidence indicating that the change will be of benefit.	Participants in a retirement plan were given the option of changing the distribution of their investments every year at no cost. Yet, despite varying rates of return among different options, only 2.5% of participants changed their distribution in any given year. When asked why they never changed their plan distribution, participants were often unable to justify their preference for the status quo. (90, 95)
Sunk Cost Fallacy Bias	Irrationally clinging to things that have already cost you something.	The tendency of people to irrationally follow through on an activity that is not meeting their expectations because of the time and/or money they have already spent on it. For example, the Concord aircraft. (92, 94)