Chapter 4: Towards a Practical Philosophy of Engineering

4.1 Introduction
An appropriate starting point for this chapter might be to consider why philosophy should enter into an engineering dissertation. Russell (1946b) argued that philosophy is the intermediary between theology and science – that all definite knowledge sits within the realm of science and that dogma belongs firmly in the domain of theology. According to Russell, philosophy occupies the “no man’s land” between the two, between definite knowledge and dogma. Engineering is a practical discipline – to be successful and to avoid catastrophe, it must rely on knowledge, not belief. A practical philosophical framework for engineering will reduce the space occupied by no man’s land, allowing engineers to engage with increasingly challenging and complex issues and with greater confidence, so that they “know” rather than “believe”. In other words, establishing a sound, practical, philosophical framework for the practice of engineering reduces the influence of dogma and belief and increases the certainty of outcome.

As Popper (1972d) notes, a further aim of philosophy is to enrich our view of the world by producing imaginative, critical argument and theories of practical interest. The aim of this chapter is to develop a set of practical philosophical principles which take into consideration the challenges of Type 3 problems in their broadest context, particularly as they relate to sustainability and sustainable development. This is intended provide a means by which the engineering profession might engage with these problems, a means which is non-dogmatic, flexible, critical and open to revision.

As the first two chapters reveal, at the heart of the sustainability discourse there lie important philosophical issues. In Chapter 2, it was argued that there are two fundamentally distinct philosophical positions underlying sustainability and sustainable development. These two positions reflect fundamental differences of belief and values and, despite considerable common ground, these differences are so profound that it is unlikely that they can be reconciled using the approaches typically found within engineering practice. In Chapter 3, a more general consideration of problem complexity was presented, showing that engineering is well suited to solving Type 1 and Type 2 problems but less well-prepared to solve those of Type 3. For engineering to be able to engage in the resolution of Type 3 problems typical of those found in the sustainability
discourse, a new approach needs to be identified. It will be argued here that this should be a critical approach, drawing upon the debate in philosophy of science of the last 70 years.

This challenge has not gone unnoticed: for example, the Royal Academy of Engineering in Britain (Ruffles (2000)), drawing upon Gibbons (1994), refers to Mode 1 and Mode 2 research. Mode 1 refers to the traditional scientific approach, whilst Mode 2 research engages with the domain of interests and involves transdisciplinary aspects, utilising a dynamic problem-solving approach. However, this stops short of the critical approach advocated here because there is no fundamental consideration of the underlying philosophical principles upon which engineering practice is based. The argument to be developed here is that the current paradigm is dated and a new set of philosophical principles must be developed to guide sustainable engineering practice in the 21st century.

The practice of engineering emerged in the early part of the 19th century and, with the industrialisation of Europe and America, by the end of the century, had become established as a professional discipline. As engineering evolved during this period, in broad terms, it went through three phases. For much of the late 19th century, engineering problems were considered largely as specific, individual instances. Problems of that era were largely Type 1 problems and the relatively simple reductionist approach, in the traditions of the Padua School, were applied with great success. In the late 19th and the early 20th centuries, there was a recognition that general engineering principles could be widely applied to families of problems. This gave rise to a new approach to engineering. For example, in chemical engineering, in the late 19th century, George Davis was instrumental in identifying a core set of unit operations which could be applied to a large number of industrial processes (Donnelly (1988)). This was significant in distinguishing the discipline of chemical engineering from industrial chemistry.

In the second half of the 20th century, engineers attacked immensely more complex problems and industrial processes with notable success. Drawing upon newly-emerging systems theory, engineering practice advanced considerably, especially in developing technologies to control highly complex systems from petrochemical plants, to power stations, to jet aircraft. The results of the extension of engineering practice to include the
systems approach has been used with extraordinary effect to solve a new class of engineering problems. These were predominantly Type 2 problems – those which were able to be modelled using analytical systems approaches.

But the problems of the sustainability discourse are generally Type 3 problems and the engineering profession has yet to come to terms with the challenge presented by this emerging problem type. In other words, the engineering profession must consider the way in which engineering practice can be developed in the context of widely differing ideas and worldviews. To address the Type 3 problems of sustainability, perhaps what is needed is not a “philosophy of science”, or a “practical philosophy of science” but rather, a “practical philosophy of engineering”. This chapter will attempt to characterise the current philosophical approach to engineering and identify the limitations of the profession in coming to terms with Type 3 problems. By comparing this with the development of the philosophy of science and philosophical approaches to scientific knowledge that have been the subject of vigorous discussion for the last 70 years or so, a set of philosophical principles will be developed to enable the engineering profession to engage with the Type 3 problem.

### 4.2 Characterising the philosophy of engineering

Although engineering is often considered to be a technological science (although not usually by engineers), there is an important distinction to recognise between science and engineering. Science is the systematic development of knowledge gained through experiment and study. The aim is to “know” so we are freed from the need to rely on dogma and insufficiently justified belief. Engineering is less concerned by the philosophical question of whether science represents a true description of reality. Rather, it relies heavily on the presumption that science provides a practical instrument with which to model the observable world and to predict and control its behaviour.

Thus engineering is by its nature instrumentalist – it seeks to use science to achieve an outcome which, historically, has been to service the needs and desires of mankind. Newberry (2006) refers to the approach of many engineers as one of “proximate instrumentalism”, noting that most engineers are not particularly reflective in the social sense about the practice of their discipline. Some see engineering as an essentially “values-free” discipline, where science is harnessed in a way which can be used for the
common good. It is argued here that this paradigm has become outdated and engineers need to consider the philosophical underpinnings of the profession critically, so as to be able to come to terms with matters of belief, values, and moral standing which characterise Type 3 problems. If engineering is to maintain its relevance as a profession or, more desirably, to re-establish the leadership it showed in the 19th and early 20th centuries, it must embrace this new problem typology and consider the philosophical and intellectual challenges in coming to terms with it. That is not to advocate a return to the engineering practices of that era but rather to learn from the past and to create a new engineering paradigm to deal with the Type 3 problems of the sustainability discourse.

4.2.1 Locked in a positivist paradigm
One problem with an instrumentalist discipline, such as engineering, is that once a scientific paradigm is established which is robust enough to provide broadly acceptable solutions to a very wide range of practical problems, there is no particular reason for the paradigm to change. The positivist approach to science developed a body of scientific knowledge around mathematics, physics, chemistry, electrical phenomena, and so on which formed an impressive foundation on which much engineering practice is still based. Unsurprisingly, the scientific paradigm upon which engineering largely relies is not too different from positivist approach which was at its most influential in the first 30 years of the 20th century, culminating in the Vienna Circle’s “logical positivism” – this is the period when much of the fundamental science which provided the basis for modern engineering emerged. It is important to understand the philosophical provenance of the logical positivist position for two reasons. First, much of the thinking underlying modern philosophy of science and the development of scientific knowledge has arisen as a result of criticism of this position. And second, if a practical philosophy of engineering is to be developed, one way of approaching this is to reflect on current engineering practice and evaluate its relevance in comparison with the development of philosophy of science, with particular attention to the discourse of the last 70 years.

4.2.1.1 Logical positivism – the engineering paradigm?
Positivist thinking had its origins in the empiricist philosophers of the 17th and early 18th centuries such as Locke, Berkeley, and Hume, all of whom were influenced by the paradigm shift in philosophy introduced by Descartes. Descartes intended to provide the
framework by which theology, metaphysics and natural philosophy\textsuperscript{47} could be unified. Within a realist ontological framework, Descartes considered the deception which occurs through the senses of the finite human subject, dealing with sceptical issues through demonstrating the existence of a God who would not allow us to be deceived. Hence, Cartesian natural philosophy of that era, unlike Aristotelian philosophy, \textit{requires} a Christian metaphysical theology in order for it to be successful (Christensen (2008)). Descartes responded to the problem of unifying this concept of natural philosophy with human thought with a partly metaphysical, partly theological, and partly scientific response. He asserted that the mind (which he identified with the soul) is entirely distinct from matter and that it can exist whether or not the body exists but because they are so closely joined, they effectively form a single thing (Descartes (1641)). Thus Descartes constructed a \textit{dualist} philosophy in which the mind and its contents are separable from physical matter.

The metaphysical arguments which have dominated philosophy since the time of Descartes have revolved around consideration of the problems which emerged from the way in which mind and the physical world relate to one another within Descartes’ philosophical framework. Descartes was strongly influenced by the emerging physics and astronomy of Copernicus, Kepler, and Galileo. Although Descartes believed that God continuously intervenes in His Creation, it is not surprising that early empirical theoreticians’ development of astronomy and mechanics profoundly influenced philosophy and the arts, with philosophers of that era coming to consider the universe as a machine, with God as the “clockmaker”\textsuperscript{48}.

\textsuperscript{47} Descartes’s notion of natural philosophy is what we now refer to as science. However he identified and distinguished between medicine, mechanics, and morals, thereby making it a somewhat different notion to our concept of science.

\textsuperscript{48} It is important to note that at about the same time that the Enlightenment provided a receptive environment for the development of intellectual thought, there was a concurrent flowering of technological skills which were the origins of engineering. Within Europe, tradesmen migrated temporarily to bring innovations back to their own countries. In 16th and 17th centuries, there were major migrations of social groups, such as the French Huguenots and the Flemish Protestants, resulting in the dissemination of the more advanced technologies of metalwork, watch-making and foundry-work. The countries which prospered in this era, such as England, Holland, Sweden, and Switzerland were those which were tolerant and receptive to new ideas. This phenomenon became the embryo of the Industrial Revolution, with the emergence of the scientific method and a concurrent development of technology through its application to what had been previously considered to be industrial “arts” (Cipolla, C.M. (1976), \textit{Before the Industrial Revolution: European Society and Economy, 1000-1700, Methuen & Co Ltd, London, UK, pp 172-181).
Locke, taking up the Cartesian notion of a distinct body and mind, concluded that “ideas” are the result of the mind’s interpretation of real things only perceivable through the senses. According to Locke, there is no innate knowledge— at birth, the mind is a piece of blank paper and all knowledge and ideas are derived from experience, either through the senses or as a product of reason (Verma (1998)). Locke attempted to develop a theory of knowledge consistent with the new scientific approach of the 17th century. But this was criticised by Berkeley who argued that the world can be interpreted purely in terms of mind and idea. He argued that in order for something to be known, it has to be perceived by a subject. Thus, the real world is dependent on human consciousness for its existence. Berkeley considered the issue of induction implicit in Locke’s approach, recognizing that resolution of this was important but could find no solution.

When Hume considered the problem of induction, he concluded that Locke’s metaphysics was only valid if his concepts of “substance” and “causality” were established dogmatically and because they could not be justified critically, they were not valid. Hence, Hume adopted the sceptical position that empiricism could not be a source of certain knowledge (Ulrich (1983c)). Importantly, Hume noted that it is wrong to associate causality with anything more than a conjunction of events in space and time— just because two events take place in close proximity in space and time does not imply a “necessary connection”. Hume believed the inference of causality was simply a characteristic of the human mind (Grayling (1998), Popper (1963b))49. Early interpretations of Hume’s work suggest that he took Berkeley’s argument to a sceptical extreme, asserting that if there is no reason to believe in physical things, there is no reason for the existence of individual mental states or beings (including God) and that both Locke and Berkeley were wrong in accepting causality.

But a more moderate interpretation of Hume’s work is that he was only sceptical about the capacity for “rationalist philosophy” to provide proof of particular propositions—that is, it is a flaw in human reasoning to use inductive logic as conclusive proof of an

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49 Popper states Hume’s problem of induction very concisely and clearly: if K represents the set of past observations which are true and logically self-consistent and B represents the set of logically possible, future observations, the two sets, K and B, can always be conjoined without contradiction. In other words, because all the members of B are logically possible outcomes derived from observations within K, no member of B can be contradictory. Hence, any theory which is an accurate predictor of future events cannot have been derived by induction alone.
argument (Grayling (1998)). Hume does not argue against the use of inference and inductive logic; he simply rejects the use of induction as conclusive proof. That is to say, induction relies on an assumption in addition to extrapolating from past events, namely that some general rule applies.

These empiricist foundations were built upon by positivists such as Auguste Comte and utilitarian philosophers such as John Stuart Mill in the 19th century. These were further developed in the analytical philosophy of Russell and Wittgenstein in the early 20th century. Habermas summed up the positivist approach as: acquiring knowledge through systematic observation; attempting to guarantee the reliability of scientific knowledge through methodological certainty; producing law-like hypotheses from formally constructed theories to provide an exactness to knowledge; using scientific knowledge to control both nature and society; and viewing knowledge as both relative and unfinished (Frisby (1976)). Russell and Wittgenstein, focused on the linguistic use of problem concepts, such as those of the material, the mental, and the abstract because they believed that the logical analysis of language would make them unproblematic. However, they reached different ontological conclusions: Russell took an empiricist position that only experiential events actually exist and that the mind and physical things are merely constructs, not independently existent, whereas Wittgenstein argued that elementary propositions reveal the general form of the world (Russell (1946c)). Popper, as will be discussed below, developed these three states (the material, the mental, and the abstract) into a powerful ontological representation of the world.

Further developing the linguistic approach, the Vienna Circle argued that sentences derive their meaning from steps taken to determine their truth or falsity. The approach was built on three axioms: first, that there is no philosophical problem in relying on empirical observation; second, agreeing with Hume, that a causal mechanism cannot be derived from a set of observations; and third, that universal laws can be found inductively and further observations can be predicted from these laws (Mingers (2000)). The logical positivists, because of their position regarding linguistic analysis, concluded that the only valid cognitive claims were either empirical (determined through science) or analytical. Thus they argued that truth-claims of religion, aesthetics, and ethics were meaningless, merely being expressions of preference or issues of practical philosophy. (Werkmeister (1937a), Werkmeister (1937b), Fotion (1995), Niiniluoto (1999e)). Thus,
the logical positivist approach saw philosophy as being analysis of language and logic, that is, how practitioners talked.

Although logical positivism has been criticised extensively (see below), much engineering has developed around the positivist philosophical position. Thus it is important to understand the strengths and limitations of this approach and current engineering practice in relation to the challenge presented by Type 3 problems. Engineers tend to accept prevailing scientific theories as being true, with deviations between observed behaviour and theoretically predicted behaviour generally being explained in terms of experimental error or other complexities which are not well understood. Much engineering design work is founded on experimentation and the construction of mathematical models which do not explicitly question either the fundamental scientific validity of the models or the underlying realist ontological framework upon which the models are based. When anomaly or error is identified, it is assumed to be a consequence of experimental method or to derive from model uncertainty. The important point is that although these models are recognised as abstractions of reality, there is no explicit engagement with the values and beliefs which influence model selection and model construction. That is to say, there is no critical engagement in the underlying values assumptions upon which the models are based. As will be noted below, other disciplines, for example, the decision sciences, have recognised the influence of the beliefs and values of the practitioner and have engaged in such a critique.

Engineering is inherently inductive, involving observation of the behaviour of existing systems and carefully extending designs beyond the experimental domain\(^50\). Just as the positivist approach was typically mechanistic and certainly atomist in nature, so too engineering relies on the reductionist approach, construing the behaviour of larger wholes as the sum or at least as being some function of the simpler behaviours of their parts. (The basic ontological structure this approach was first \textit{de facto} expounded as the so-called Padua method – see Randall (1940).) Even in the systems area, emphasis tends to be on the reduction of complex systems to workable subsystems so as to make system control methodologies practical.

\(^{50}\) Engineering catastrophes are often the consequence of inductive reasoning turning out to be invalid.
At first glance, this approach appears to be not only sensible but perhaps the only way in which engineering can be practised. There must be clear, rational, scientific principles underlying engineering design and provided these principles result in a practical solution to the problem and the limitations of the principles are understood, the desired outcome should be achieved. For many of the problems on which engineers have worked in the 19th and 20th centuries this approach was reasonable. But, as noted above, most were either Type 1 or Type 2 problems, which could be readily described using established scientific theories and models which, history suggests, have been accurate enough for this approach to have been successful. But the Type 3 problem, with its values-laden characteristics, its immense complexity, which, more often than not, defies holistic modelling, presents a significant challenge to the traditional, positivist engineering approach, still based largely on the Padua method. Other difficulties with Type 3 problems which emerge from using this paradigm are that assumptions made inductively outside the problem boundaries are often found to be wrong and there may be widely conflicting scientific theories under development to explain certain aspects of the problem. Furthermore, models constructed on these theories may produce divergent results; social and political influences may overwhelm the technological issues; and the traditional anthropocentric engineering solution may not be acceptable in a broader moral context. In addition, the reductionist approach, by its very nature, tends to discard those things which are, or appear to be, incommensurate with the commonly accepted means of defining the problem. Hence, issues around values, the influence of beliefs (other than those which are scientifically based), and the aesthetic aspects of the problem, are either discarded from the problem definition or marginalised.

But perhaps the most significant deficiency of the instrumentalist engineering philosophy is that it tends to be non-critical. Hence, engineering practice struggles to include aspects of the problem which do not have some form of scientific basis (that is, things that we know) and because of this deficiency, it can overlook critical, non-technical influences on the problem. There is no established critical engineering approach, other than various forms of stakeholder engagement and consultation which have evolved in the last 20 years and which rarely prove to be satisfactory.

These issues will be now explored further to develop a set of philosophical principles for the practice of engineering, the aim being to provide a foundation for the framing or
structuring of the highly complex Type 3 problem, so that not only the content of the problem is identified but that this takes place within the broad social and moral context in which the problem itself exists. The way in which this is approached is to consider the extensive postpositivist discourse on the philosophy of science which took place in the last 70 years and, in particular, the influence of German idealism, critical theory, and cultural theory in this discussion.

4.3 Science and scientific knowledge after logical positivism

4.3.1 The post-positivist debate

Since the 1930s, the logical positivist position has come under attack from a number of quarters. There have been several important discourses around the philosophy of science: philosophers, anthropologists, sociologists, and scientists have brought very different perspectives to the forum in considering the development of modern science. The first attack came from Karl Popper, who sharply disagreed with the logical positivist approach.

While the positivist conception of reality that the world is fundamentally atomistic and mechanistic; a complex, intricate machine created by God, Popper’s thinking was drawn to Kant’s consideration of Hume’s problem of induction. Kant was intrigued by Hume’s sceptical conclusion that, because cause-and-effect are nothing more than a conjunction of events in space and time, and because our knowledge is dominated by repetition in argument, rather than by analysis, much of our knowledge is exposed as “irrational faith” (Popper (1972h)). According to Popper (1963b), Kant’s great insight was to realise that, contrary to Bacon’s view that science proceeds only by observation, the scientist must interrogate nature, following a plan formulated by reason. Reflecting on Hume’s observation regarding the logical impossibility of induction as proof of knowledge, Kant concluded that everyday experience cannot be based only on observation – notions must be introduced which cannot be inductively derived from observation alone. For example, Kant, while believing Newton’s theory to be true, recognised that Newton could not have formed his theory inductively (contrary to Newton’s own stated belief) and proposed his “theory of experience and natural science” to resolve this paradox.

According to Kant, while we can learn about many aspects and laws of nature by observation, we cannot understand the most fundamental laws of matter, space and time.
Rather, we assume some notion of reality to conform to these laws thereby making it possible to do the kinds of experiment from which we can discover and justify less fundamental and less general features of nature. In other words, we make certain fundamental assumptions about reality in order for us to be able to justify generalisation from empirically determined facts and events to more powerful, underlying explanatory theories\(^{51}\). Hence, Kant’s interpretation of the empirical unknowability of cause and effect argued by Hume was an expression of this: namely, that the notion of cause and effect being a consequence of some causal law is simply an assumption we must make in order to be able to generalise meaningfully from the conduct of experiments. Kant rejected the empiricist view, held by Hume, that all knowledge comes via the senses. Instead, he argued that all things consist of the “phenomenal” (appearances or “things-for-us”) and the “noumenal” (or “things-in-themselves”). According to Kant, we can only know the noumenal to the extent to which they impact upon our senses via the phenomenal, otherwise they are unknowable. Kant (1724) argued that we can acquire “transcendent” knowledge\(^{52}\) of the noumenal, although they are hidden from us, through thought and critical argument (Niiniluoto (1999f), Ulrich (1983c), Gardner (1998), Smith (1918)).

Although Popper was influenced by Kant, in some areas he had distinctly different views. Popper placed emphasis on Descartes’ hypothetical-deductive approach, that notions such as causality were suppositions made not as inductively created hypotheses but as assumptions which enabled a specific line of experimentation. Their purpose and justification was to create ever more powerful theories which would allow us to develop knowledge purely from our ability to reason and without reference to experience (Popper (1940)).

Popper’s views on philosophy of science have been referred to as “critical rationalism” or “critical realism”. Popper was not the first to attempt such an approach – R.W. Sellars (1924), Lamprecht (1922), Drake, Santayana and others (Drake and Santayana (1921))

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\(^{51}\) This became known as Kant’s “Copernican revolution” and in much of the literature Kant is accused of being less than modest in using this comparison. It’s interesting to note that in “The Critique of Pure Reason”, Kant does not refer to a Copernican revolution at all, rather he uses reference to Copernicus as an example of how, when progress is difficult under one set of ideas, by entirely changing perspective, as Copernicus did, progress can often be made.

\(^{52}\) Smith notes that Kant borrowed the terms “transcendental” and “transcendent” from Scholastic philosophy of the middle ages where they had an almost mystical connotation, representing concepts which transcend or go across categories, for example, as given by Aquinas to the Father, the Son, and the Holy Ghost.
had attempted a critical realist approach in America in the early 20th century – but Popper, with his theory of conjectures and refutations, advanced the argument substantially and stimulated considerable thought on the subject. Kuhn, while acknowledging much common ground with Popper (Kuhn (1970)), suggested that science progresses through a series of relatively rapidly occurring paradigm shifts, which are not unlike Gestalt switches (Kuhn (1962)). During the long periods between paradigm shifts “normal science” proceeds, investigating phenomena within the prevailing paradigm. As normal science progresses, outcomes of scientific research start to identify inconsistencies within the current paradigm and dissatisfaction builds to a point where a new theory is proposed which establishes a new paradigm.

Feyerabend (1975d), Feyerabend (1975e), on the other hand, argued that “anything goes”. He proposed that rather than being prospective, scientific discovery does not follow a particular methodology. Rather, the rigorous application of criticism and proof is retrospective, with the subsequent construction of theory being derived from the examination results. Feyerabend argued that science is replete with examples of methodological rules being ignored. This does not mean that science is irrational: this would only be the case if one were to confuse two contexts, one of discovery, which is largely intuitive; and the other of justification, which proceeds in an orderly manner after discoveries have been made. He gives examples that suggest that even the greatest scientific discoveries, such as Galileo’s invention of the telescope, contained elements of politics and propaganda.

Lakatos (1974) was concerned about the “demarcation problem” explored by Popper: how do we determine the distinction between science and pseudoscience, noting the importance of politics in determining scientific outcomes. Lakatos (1978) proposed that scientific progress comes as a result of “research programs”. The characteristics of a research programme are its “hard core” of theoretical presuppositions which are guarded by the “negative heuristic”, a mindset which prevents attack of the hardcore by \textit{modus tollens}^{53}. This forms a “protective belt” around the core and it is these against which \textit{modus tollens} is directed. The “positive heuristic” guides the development of more and more complex models which explain reality.

\textsuperscript{53} The rule of logic that states that “if \( p \) then \( q \)” is true, then “if not \( p \) then not-\( q \)” also holds.
Together with other criticisms (e.g., Hacking (1981a), Hacking (1981b), Putnam (1981)), these philosophers recognised the inability of the mechanistic model to deal with fundamental uncertainty of the world, the effect of human cognitive limitations and the influence of beliefs and values on human thought. Importantly, they rejected the positivist assumption of a truly independent observer. Popper’s conception of science as conjecture and refutation is built around the rational, individual scientist proposing a theory and a greater community of scientists attempting to refute it (Popper (1976a)), whereas Feyerabend and Lakatos do not accept such a measured, structured approach—they argue that science advances by a process which is far more “anarchic” and political in nature (Feyerabend (1975a), Lakatos (1999)).

Several issues of importance to engineering practice have emerged from the critical, post-positivist position created by this discourse on philosophy of science. Engineering work is often undertaken under an implicit assumption that the engineer provides a service or technological solution from a detached, independent position. One of the conclusions from the discourse on philosophy of science was, however, that there can be no such thing. The positivist assumption of an observer, truly independent and detached from the problem is unachievable. Engineers, like all participants in the problem space bring their own individual beliefs and values to the situation. This lack of fundamental independence on the part of the engineer cannot be ignored and, indeed, brings particular obligations to the practising engineer in terms of professional integrity. Practising engineers must relate to beliefs and worldviews which may be in sharp contrast to their own. Engineers encounter political and social issues and because of the presumption of engineering independence, these issues are usually seen as barriers to progress. What is often overlooked is that values, politics, propaganda and other issues are part of the fabric of human interaction and are woven into the scientific process and, implicitly into the practice of engineering.

The advantage of taking a critical position to the acquisition of scientific knowledge has been a key theme of this discourse. One of the fundamental insights provided by Kant was that although the noumenal is forever hidden from us, through critical thought we can form justifiable beliefs about things-in-themselves (although Kant did not believe that this constitutes real knowledge). Thus, engineers engaged in Type 3 problems found in the sustainability discourse are committed, by the very nature of knowing in its fullest sense, to reflect deeply
upon the structure of the problem – in particular, the extension of the problem dimensions to include the complete domain of interests. Implicit in this is the need to question the assumption underlying current engineering practice that it is value-free, is detached and independent from the problem, and is confined to the technological. Furthermore, engineering practice must be extended to include the norms, values, and aesthetic judgements of those with moral status in the problem under consideration.

The Popper, Kuhn, Feyerabend, Lakatos debate was largely around the development of the natural sciences. Although it had a distinctly critical flavour, another school of thought, which emerged under the influence of Kantian philosophy, argued that the “critical rationalist” approach of Popper and many other philosophers of science was inadequate, particularly where the social dimensions of problems are important. This second source of criticism of the positivist position arose from an entirely different strand of European philosophical thinking, emerging from post-Kantian German idealism. The philosophical issues identified by these social theorists, anthropologists, and cultural theorists will now be considered. This thinking was highly influential in contemporary philosophy of science and is important in the development of practical philosophical principles of engineering because it provides the means to incorporate aspects of the Type 3 problem. These are not readily dealt with using purely scientific and technological approaches.

4.3.2 The influence of German idealism – Critical Theory and Social Theory
Two groups which have been particularly influential in the development of a critical approach are the Frankfurt School and Edinburgh School (Brocklesby and Cummings (1996), Mingers (1980), Kincheloe and McLaren (1994), Niiniluoto (1999c)). Both emphasise the interrelationship between the observer and the observed, taking into account the sociological influences in the acquisition and interpretation of knowledge. Like Popper, they have their origins in Kantian philosophy. As noted above, Kant sought to understand how it is that the human mind is able to understand the world, concluding that this is because our representation of the world is formed through our imposition of a categorical framework on our sensory experiences. That is to say, our representation of the world assumes characteristics imposed by our minds. Kant’s approach was a synthesis of naive realism and subjective idealism in the tradition of Berkeley. While Popper’s critical rationalism develops the realist dimension of Kant, the sociological approach develops the German idealist interpretation following Kant,
particularly Fichte, Schelling, and, most importantly, Hegel. Hegel developed the idealist aspects of Kantian theory, not simply accepting that our mind forms perceptions of reality, as Kant had proposed. Rather, Hegel concluded that the representations imposed on our perceptions are the ontological structure of reality itself. Hegel maintained that there was no sceptical possibility that our representations might not be forms to which reality itself conforms. In this sense, there is no distinction between reality and thought (Popper (1940), Popper (1963a)).

The Frankfurt School originated in the 1930s at much the same time as the Vienna Circle was at its height. Its proponents, Horkheimer, Adorno, and Marcuse, and later, Habermas, developed critical theory, following an entirely different course to that of the positivists. Critical theory draws upon Hegelian idealism, the Marxist notion of a utopia resulting from natural consensus and unification of man, nature, and history, together with elements of psychoanalysis (influenced by William James) and existentialism. It developed the proposition that the Enlightenment stalled the emancipation of mankind and its aim should be resurrected to emancipate, to level unequal power, to call upon mankind’s fundamental goodness, and to use knowledge to eliminate inequality (Brocklesby and Cummings (1996), Mingers (1980), Ponterotto (2005), Kincheloe and McLaren (1994), Niiniluoto (1999b)). Critical theory placed an emphasis on the social nature of knowledge and although it had a substantial influence on the discourse on philosophy of science, it does not appear to have had a particular impact on the practice of engineering.

However, there are two respects whereby the contributions made by critical theory to the philosophy of science are important in developing philosophical principles for sustainable engineering practice. First, a lively discussion developed between Popper, Adorno, Albert, Habermas and others in relation to the positivist approach, considering whether it could be satisfactorily extended to, or applied in, the social sciences (Frisby (1976), Adorno (1976), Habermas (1976), Albert (1976)). Popper rejected the positivist label and formulated a set of theses suggesting the way in which his critical approach could be applied to both the natural and social sciences (Popper (1976a), Popper (1976b)).

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54 Frisby (1976) notes that German social science theory evolved from two neo-Kantian schools of thought. The first of these was the South-West School (whose proponents were Windelband and Rickert) who focussed particularly on the “historical and cultural sciences”. The second, the Marburg School (whose proponents were Cohen and Natorp) explored the logical foundations of the natural sciences.
Ulrich (1983a))\textsuperscript{55}. This debate brought a critical dimension to the social sciences which had not been recognised by the logical positivists, yet preserved the logical positivist goal of construing the natural and social sciences as not being fundamentally different from one another. \textit{For engineering practice to be effective in dealing with the Type 3 problems of the sustainability discourse, such a critical approach is of the utmost importance.} And second, Habermas’ later work, particularly his “theory of knowledge-constitutive interests” and his “theory of communicative action”, have been influential in the approaches of the decision sciences (particularly, operational research) towards solving highly complex, “messy”, social problems (for example, see Ulrich (1988), Ulrich (1983d), Ulrich (2003), Mingers (1980), Brocklesby and Cummings (1996), Gregory (1996), Valero-Silva (1996), Jackson (1985)). These problems might be thought of as the precursors to the Type 3 problem of the sustainability discourse and have been incorporated into a critical systems approach. This suggests that a potentially fruitful avenue of investigation for the practice of engineering could be to develop a critical, less instrumentalist philosophy, extending its systems approach beyond the purely technical into the arena of the social sciences, so as to increase the relevance of engineering practice in the solution of Type 3 problems encountered in the sustainability discourse.

A somewhat different approach to sociological influences on knowledge was taken by Mannheim but less influenced by the Marxist approach of the Frankfurt School (for an overview of Mannheim’s contribution, see Kettler et al. (1990)). Mannheim’s work was noted by Merton and both were influential in developing an Anglo-American concept of the sociology of knowledge. Merton (1937) notes that Mannheim’s approach was to examine human thinking in its political context “as an instrument of collective action” rather than the normative way in which it is often described. Mannheim believed that considering the sociology of groups in which scientists interact may identify different ways of thinking which are specifically related to the group and that the way in which knowledge is categorised reflects the social position of the observer.

\textsuperscript{55} Popper criticised positivism based on the objections raised by both Hume and Kant. But Popper was both a realist and a rationalist – he believed there exists a world independent of the mind and the way we can understand our place in the world is through rational thought and criticism. This criticism was largely framed around examination of the natural sciences and Popper recognized that the independence of the observer is never complete in the natural sciences and even more of a problem in the social sciences. But Popper’s critics did not believe his treatment of the social sciences was adequate and that his approach would lead to social engineering and people becoming “inmates of closed institutions” (Ulrich (1983a)).
Related to this line of thinking, the Edinburgh School’s (thinkers such as Barnes, Collins, and Bloor) approach to sociology of scientific knowledge (SSK) tries to explain how scientific knowledge develops in a social context, rather than specifically defining a normative ontological and epistemological framework (Friedman (1998)). Bloor’s “strong program” (Bloor (1973)) was extensively criticised (for example, by Laudan (1981), Laudan (1982)). But his more recent approach (Bloor (1981), Bloor (1996)) emphasises that the important issue is that scientists use a set of organising principles and rules for structuring their knowledge; their senses give rise to their perceptions of the world but their inductive and deductive reasoning is built around culture. In other words, knowledge of reality is achieved through society, not despite it.

The influence of the study of the sociology of scientific knowledge is important in considering engineering practice for two reasons. First, it has investigated the way in which the scientific community is structured and has explored how social influences work as scientific knowledge is acquired. It has investigated the influence and goals, of reward systems and the way in which controversies are resolved. It has also considered the influences at play in determining the importance of scientific work, and where it is published (Niiniluoto (1999c)). In so doing, it has highlighted the social nature of scientific research and has largely dispelled the notion of the independent, objective practitioner. This point is accepted here as being entirely relevant to engineering practice. However, the second is largely rejected. SSK has considered the role of the scientist – and by analogy, the role of the engineer – in society, reflecting upon both the way in which science influences modern institutions and how policy is developed. Although SSK provides plausible insights into the social influences at work in the development of science and the behaviour of scientists (and of engineers), the foundation of SSK is both constructivist and relativist. Extended to its logical conclusion, this ontology argues against external realism which, as will be argued more fully below, is the ontology which underlies engineering.

Nonetheless, many of the issues identified in the consideration of the sociology of scientific knowledge also apply to engineering. It is clear that engineers cannot reasonably consider themselves to be independent of the problem, so there can really only be two courses open. Either disengagement from the non-technological aspects of the problem; or a more complete, holistic engagement, not simply as an engineer but
rather as an honest citizen seeking to identify the most appropriate, technologically feasible outcome to satisfy the problem requirements\textsuperscript{56}. Implicit in this is a realisation that in many of the complex problems of sustainability and sustainable development, consideration is required of a much broader portfolio including beliefs, values, moral status and so on. This presents challenges which many engineers are ill-equipped to meet.

4.3.3 Postmodernism
A more radical approach still is the postmodernist view, expressed by Foucault, Lyotard, Derrida, and others, which questions the principles upon which all modernist rationality is based. Postmodernism is not a specific movement in itself, rather it is an aggregation of many views. However there are two distinct streams of thought which can be identified: one which sees modernism as amoral because it holds us hostage to imbalances in power – and another, reactionary form, which seeks to address the uncertainty of the human construct of modernity by returning to some utopian, authoritarian “golden age” (Jackson and Carter (1991)). Both share similar characteristics. Postmodernism questions whether language has the capacity to represent “truth” in the world in terms that are objective and transparent. It questions whether we can separate ourselves from our “referentialist representation” of what appears to be reality (Merrill (1995)). As with each of the philosophical positions briefly explored here, postmodernism also has its origins in Kantian philosophy. Of particular importance in the postmodern approach is the post-Kantian philosophy of Nietzsche, Heidegger and Foucault, interpreting the rules of critical thinking as being self-imposed tutelage or as a false characterisation of critical thinking and operational subjectivity in general. Postmodernism interprets the “rational” as an unreasonable desire to favour the “normal” over the “abnormal”. It argues against the phenomenon of modernity which the postmodernist sees as nothing more than a human construct used to interpret occurrences and beliefs as being logical and natural (Cooper and Burrell (1988)). Postmodernists such as Foucault, Derrida, and Baudrillard (see Mingers (1992)) reject the notion of attempting to address progressively social issues, of perfecting understanding through language and communication, and attempting to arrive at an underlying reality.

\textsuperscript{56} There are certain similarities between the “engineer as a citizen” position argued here and the “honest broker” role outlined in Mitchell et al. [in Azapagic, A., Perdan S., Clift, R. (2004) Sustainable development in practice: case studies for engineers and scientists; Wiley; Hoboken, NJ]. A not dissimilar argument for the “new engineer” is made also by Beder [Beder, S. (1998) The new engineer: management and professional responsibility in a changing world; Macmillan Education Australia, South Yarra Australia.]. However, significant points of distinction are made later in this chapter (see footnote 69).
Rather, they believe that the universe is made up of contradictions and difference and that language and knowledge are nothing more than superficial, anthropocentric means to come to terms with this chaos.

At least in decision science, postmodernist views have not been as widely influential as the Frankfurt School’s critical theory and the social constructivist approach of the Edinburgh School outlined above. It is mentioned here because there has been some consideration of postmodernist influences in operational research, which itself has been a significant influence in the development of the problem taxonomy described in Chapter 3. (For relevant discussion of postmodernism in operational research, see Mingers and Brocklesby (1997), Mingers (2000), Flood and Romm (1996), Fishman (1995), Schwandt (1994), White and Taket (1996), White and Taket (1994).)

4.4 Insights from the philosophy of science discourse and critical theory

Before proceeding further, it might be useful to briefly summarise the discussion to this point and to outline the direction to be taken in the remainder of this chapter. At the start of the 21st century, the practice of engineering is largely framed around the positivist approach to science which reached its zenith in the 1930s. Although the philosophy of science has taken a critical direction over the last 70 years, there has been no corresponding development of a “philosophy of engineering”. One consequence of this has been increasing public discomfort with some aspects of engineering work. Of particular concern is the Type 3 problem, where the application of the reductionist approach excludes important aspect of the problem situation. In the 20th century, the development of philosophy of science and the practical application of philosophy to highly complex problems has developed within two paradigms. On one hand, there is what is referred to here as the scientific approach. Although the scientific approach has its origins in early empiricism and has a positivist lineage (the most extreme form being the Vienna Circle’s logical positivism of the 1930s), in the latter half of the 20th century it took a distinctly critical turn. The discourse exposed the influence of uncertainty and complexity, the limitations of the reductionist approach, and a recognition of the influence of the practitioner. On the other, there is the approach, based on critical theory and social theory, with its origins in German idealism, particularly influenced by the thinking of Hegel and Marx. A more

57 Opponents often refer to this as the “scientistic” approach, using the term disparagingly in reference to the logical positivist view of science being omnipotent both metaphysically and in its application to both the natural and social sciences
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extreme form is social constructivism, typified by the approach of the Edinburgh School, which emerged concurrently with the even more radical postmodernist approach.

The key assertion made here is this. These two broad approaches – the scientific avenue on one hand, and the critical or social approach, on the other – are considered here because, despite there being very substantial philosophical differences between them, both are relevant by virtue of the contribution they can make to the practical resolution of Type 3 problems found in the sustainability discourse. Before embarking on how the differences in approach might be addressed in such a way as to make progress, at the centre of the debate there are important similarities and common ground which should be identified. First, both are framed around the existence of a physical, mind-independent real world. That is, both can be considered to be ontologically realist. As Niiniluoto (1999e) points out, there are different types of realism, but both scientific theorists and social theorists are concerned about problems manifested in a real world. Second, both accept the notion of “wholeness” proposed by Hegel, namely, that individual elements of an issue cannot be understood in isolation but must be considered within the entirety of the whole. In addition, and of particular importance, the uncertainty in system outcomes is recognised. That is, both approaches recognise system complexity and uncertainty. And third, in the last 70 years (after Popper, at least) the discourse has largely been critical, following the Kantian transcendental approach. It would be wrong to infer from these similarities that the areas of contention between the two are trivial – far from it; there are significant philosophical differences between them. However, it is asserted that drawing upon the similarities, while not overlooking the differences, enables insights to be identified which are important in developing the practical philosophical principles of engineering which are sought after here. The remainder of this chapter will attempt to draw upon these two quite different approaches in order to construct a consistent philosophical position which entails a set of philosophical principles of practical use to the engineering profession in considering the Type 3 problems of which emerged from the sustainability discourse.

58 It should be noted that the “critical” approach used by philosophers of science although based on Kant’s concept of critical thought is quite different to it. Kant’s notion of critique requires that philosophy is constantly criticising its own self-conception. Hence, there can be no philosophical parallel to Kuhn’s concept of “normal science”.

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4.5 Towards a practical philosophy of engineering

4.5.1 Development of an ontological and epistemological framework

A useful way to consider the issues emerging from the observations in the first part of this chapter is one developed by Popper (and also somewhat differently by Habermas): the notion of “Three Worlds”.

Popper argues that the dualist mind-body ontology of Descartes is not a sufficiently rich representation of the way the world is. He goes on to define a pluralist philosophy in terms of three “ontologically distinct sub-worlds” (Popper (1972f), Popper (1972g)). The first World is that of physical states; the second is that of mental states and the third is the World of objective thought. World Two can interact with World One and World Three, but World Three can only interact with World One, by means of interpretation through World Two. Hence, one can view the mind as being the means by which objects of thought, theory, argument and so on (being of World Three) are linked to the reality of World One, with objective knowledge only related to reality through subjective interpretation. According to Popper, one of the mistakes made by many philosophers has been to interpret objective thought as being subjective, that is, a part of World Two rather than as part of World Three. Some things, for example language, belong to all three Worlds: the physical symbols of language belong to the first World; the subjective expression of ideas to the second World; while the objective aspects, such as theories and argument described by language belong to World Three. Even though the contents of World Three are a human creation, it exists before we become aware of it through our experiences in World Two – for example, prime numbers exist, irrespective of whether or not they have been recognised in mathematics.

Although some philosophers have argued that there are only two worlds, the real and the subjective, Popper's position is that the nature of, for example, mathematics clearly demonstrates the existence of the third World. Although mathematics was a discovery of man, it is autonomous. There are many problems that have been discovered by research into mathematics and many more that remain undiscovered.

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59 Popper distinguishes between two different senses regarding knowledge and thought. World Two knowledge is thought in the subjective sense – it is our states of mind, our consciousness, our intentions. Popper refers to this as “subjective knowledge” but a better term might be “subjective knowings”. World Three knowledge is, as Popper describes it, “knowledge without a knowing subject” – it is knowledge which exists independent of the subjective mind or, in other words, it is the objective content of thought.
Popper clearly intended his Three-Worlds approach to be ontological. But how are we to know that there is not an infinite number of different types of subjective knowings and objective knowledge in the universe (or universes)? Popper acknowledges that there is no particular reason why the number of Worlds should be limited to three and this weakens the ontological proposition somewhat. However, it is not the intention here to offer a distinctly philosophical defence of Popper’s position. Rather, it is accepted as a satisfactory ontological framework to enable critical examination of the issues identified above and to think about how we might structure our knowledge of the real world.

In his theory of communicative action, Habermas also conceives of three worlds, with speech acts referring to the “external world”, that is, the real world about which we can make statements and explore their truth and falsity. Speech acts can also refer to our “own inner world”, that is, they can express our own inner feelings and intentions which can either be truthful or untruthful in what is expressed. Further, speech acts can refer to our “social world” in relation to cultural and social patterns, that is, they are regulative in that they communicate things as either being “right” or “wrong” (Ulrich (1983b)). Habermas’ three worlds do not correspond exactly with Popper’s (Habermas’ social world is not the same as Popper’s world of objective knowledge) nor is it suggested here that Habermas’ intention was to propose his three worlds as being an ontological framework, in the same way that Popper did. But in a practical sense, the two approaches have similarities which might be useful in considering and structuring complex problems. (For further discussion regarding Habermas’ three worlds in the operational research context, particularly regarding complex problem formulation, see Mingers and Brocklesby (1997), Mingers (2001), and Midgley (1996).)\(^60\)

There are two implicit, underlying ontological propositions which, as noted above, are consistent with both the scientific and social theoretical approaches and which emerge from Popper’s “Three World” model: its realist ontology; and a recognition of system complexity and uncertainty. Both are important for the development of the framework for the practical philosophy of engineering developed here.

\(^{60}\) Mingers and Brocklesby formulate a diagrammatic representation with the individual mediating between Habermas’ three worlds. This is contrary to Popper – Worlds One and Three can interact directly with World Two, but World One cannot interact directly with World Three.
4.5.1.1 Engineering practice – based on a realist ontology

First is the contention of ontological realism – where a physical world exists independent of the human mind. The only justification of this to be made here is framed around a common-sense argument. Consider, for example, the Taj Mahal. I have seen photographs and drawings of it, I have read rich descriptions of its architectural detail and beauty and I have visited it and walked through it. The experiences I sense when I visit the Taj Mahal are consistent with the images and mind-representations I have formed from photographs (made by different means, for example, digitally or the silver halide negative/positive photographic process), from paintings, etchings, and drawings that I have seen and from the vivid word-descriptions that I have read. The experience I have as I visit the Taj Mahal simply adds depth and richness to my mind-representation. When I see the Taj Mahal, the experience is much greater than when I close my eyes and imagine it, suggesting that there is more to the Taj Mahal than a simple mental representation. Commonsense suggests that it is absurd to propose that were I to cease to exist so too would the Taj Mahal. As noted above, there are various forms of realism, some stronger than others, and these are well dealt with and justified in such work as Popper (1972a), Schwandt (1994), Niiniluoto (1999e), Churchill (1944), Haack (1987), Putnam (1977), Niiniluoto (1999b), Popper (1940), and Searle (1995a).

In one sense, this position might be referred to as “naive realism” that is, the notion that a physical world exists to which the human senses give us direct and immediate access. This would be true if the ontology were able to be applied to all three Worlds. However, the powerful neo-Kantian argument discussed earlier that subjective knowings and objective knowledge (that is the knowings and knowledge of Worlds Two and Three) are both subject to social influences and interpretation means that we must be critically realist about those things which belong to World Two and to World Three. In other words, the distinction is made between things which exist in the physical world and our subjective and objective representations of them. That is, we are naively realistic about things which exist in Popper’s World One but critically realistic about the contents of Popper’s World Two and World Three.
4.5.1.2 Indeterminacy and systems

The second contention is the complex nature of the world\textsuperscript{61} where many of its physical and social characteristics are best represented by the notion of “system”. This proposition can be concisely stated in these terms. Within this real world composed of what we understand to be “matter”, there appear to be arrangements of this matter which have emergent properties and relationships which cannot be described adequately using the reductionist approach. There appear to be “systems” in which the identifiable constituent parts interact in distinctive, irreducible ways, both with themselves and with other systems. In particular, some of these systems behave in ways which we characterise as having the properties of “life”. Some of these forms of life or “living systems” have the capacity to perceive and to interact with their surroundings, that is to say, they are “sentient”. Furthermore, some of these sentient organisms have the capacity to think – they are “cognizant” – and beyond this, some are also “sapient”, that is, they are capable of self-conscious deliberation.

As far as we know, human beings have the most developed capacity for self-conscious deliberation and, as a result, for the formation of social systems possible only for beings capable of such deliberation. The sapient nature of the human life form is an emergent, evolutionary feature, which imparts to our interactions with other beings the character of

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\textsuperscript{61} There is an important distinction to make between a several concepts referred to here which relate to the behaviour of systems. These relate to “complexity”, “uncertainty”, “indeterminacy”, and “imprecision”. In this dissertation, the terms are used with following meanings. Complexity is the feature of systems (which von Bertalanffy (1950) identifies in general system theory), regarding the nature of interrelationship between system elements and the behaviour of the system as a whole. One part of the system influences all other parts and interactions need not and, indeed, tend not to be linear. Manifestations of complexity include the multi-scale behaviour of systems, the emergence and formation of patterns, the dynamic response of the system, the apparent adaptiveness of systems to change, and their “embeddedness”.

Uncertainty comes from three sources: one is the uncertainty of the type which Heisenberg (1933) envisaged and is a fundamental property of the universe. (Heisenberg asserted that we cannot know simultaneously the precise mass and exact location of a particle.) Because of this we can never exactly determine the state of the universe. The second type of uncertainty arises from the unreliability of our representations of the way the world is. And third is our ignorance of the way the world is, both in terms of what we do not know and what we cannot know. Funtowicz and Ravetz (1990) refer to these three as being technical, methodological, and epistemological types of uncertainty respectively. Morgan and Henrion (1990) take a similar approach.

In the case of von Bertalanffy’s (1972) real systems, indeterminacy is a consequence of technical uncertainty. Because the precise state of the universe cannot be known, the universe cannot be deterministic. For von Bertalanffy’s conceptual systems, that is, those which are a product of human thought, there are not “exact” or “ideal” solutions, only “good” or “bad” ones according to the values of the decision-maker or decision evaluator. Imprecision is a manifestation of indeterminacy but at a higher level. It could arise from technical or methodological uncertainty. For example, a clock can never be exactly accurate because of the tolerances that exists within its mechanism – even at its most fundamental level, Heisenberg uncertainty would lead to imprecision.
being “evaluable” in terms of being wise or unwise, good or bad, right or wrong, just or unjust and so on. It is this sapience from which World Two knowings and, in particular, World Three objective knowledge emerge. A key point here is that the world does not simply consist of World One systems, but where sentient, and in some cases cognizant life-forms are present, there emerge highly complex socio-physical systems with World One, World Two, and World Three constituents.

To gain further insight into the way in which this systems approach developed, it is useful to examine the philosophical approach to the nature of reality and its reducibility to constituent elements as it evolved in Western philosophy. Greek and Roman philosophers (for example, Aristotle in *Metaphysics* and Lucretius in *De Rerum Natura*) recognised the difference between an aggregation of parts: for example, the difference between the head, legs, tail, and body forming a horse and a stack of logs forming a wood heap. But as Feyerabend (1975b) suggests, worldviews alter considerably over time (this is an important point and will be developed further in the consideration of narrative in Chapter 5). Insight can be gained into social paradigms through consideration of representations of the prevailing worldview through social artefacts, such as art and language. For example, ancient Greek art appears to be a “paratactic aggregate” – an aggregate of elements which are placed in a scene but which are not fully integrated. It seems reasonable to assume, as Feyerabend suggests, that the artistic style accurately represented the worldview of the artist. Similarly, Feyerabend points to the structure of Greek language as being paratactic rather than integrative and Greek theology consisting of many gods rather than being monotheistic. This suggests that Greek ontology was largely elemental. Feyerabend gives the example of a scene in ancient Greek art of a lion eating a kid, showing the ferocious lion eating a kid with a serene expression. Lions are ferocious; kids are peaceful. The picture is able to be read: the ferocious lion, the peaceful kid, the lion is eating the kid. The style is effectively a list of elements which are arranged in some way and then can be read, rather than being seen as an allusion representing the whole scene. Greek philosophy was the major influence on mediaeval Christian philosophy until the beginnings of the scientific revolution. Up to that time, arguments relating to determinacy tended to be theological in their nature, revolving around man’s relationship with God and the extent to which freewill existed, within the *Aristotelian elemental ontology*. That is to say, the prevailing worldview up to the time of the Enlightenment was that the world consists of an aggregative, purposeful whole. Thus,
the interest of philosophers was largely focused on teleological and theological questions concerning the purpose of man’s existence.

When the scientific revolution began, a paradigm-shift took place and a new worldview emerged, that of nature being entirely explicable in terms of its material properties. That is, the universe consists of properties and relationships between its constituent elements and these could be identified and studied using the emerging modern science. In developing and elaborating this conception of reality, figures such as Bacon, Newton, Locke, and Hobbes contended that the world was both atomistic and mechanistic – a complex, intricate machine created by God. At this point, natural philosophy changed from being teleological to ateleological – rather than asking the question “why” with the meaning “what is the purpose of this situation?”, the meaning became “what circumstances changed to make this situation occur?” (Russell (1946a)). This marked a change in natural philosophy, transforming it into what we now refer to as “natural science”.

Within this new ontological view of the world, to understand how the whole works, you must first understand how the elements interact with one another. This led to the reductionist problem-solving approach of construing the behaviour of larger wholes as the sum (or at least some function of) the behaviour of their parts, the first explicit statement of this concept being the Padua method noted earlier. Even Kant argued that if we were to have full knowledge of our physiological and psychological condition, together with a fully characterised environment, we would be able to predict future events with the same precision with which the practical application of Newton’s theory can predict astronomical events (Popper (1963b)). But Hegel, drawing upon Kant’s critique of judgement, together with others in the German Romantic movement, such as the poet Goethe, and thinkers such as Herder and Schelling (Taylor (1975)), argued that many phenomena in the world cannot be explained in purely mechanistic terms. Hegel argued that the world only exists in its totality: it is not a collection of “hard units”, an aggregation of elements (Russell (1946c)). In the sciences, Popper (1972b) notes that C.S.Peirce, although not questioning Newtonian mechanics, was the first philosopher to question the mechanistic paradigm when he suggested that all clocks are subject to at least some imprecision and hence uncertainty must enter into their behaviour. By the 1920s, work in fields as disparate as biology (Lillie (1927)) and quantum mechanics (such
as the exposition of Heisenberg’s uncertainty principle\textsuperscript{62}), revealed the need for a new means to understand nature – a concept that could embrace physical indeterminism and also could represent the interactive “wholeness” of nature. The result was the emergence of the \textit{systems} paradigm.

Popper sums this up in his observation that “all clocks are clouds” – even the most accurate of clocks have fundamental imprecision in their structure and uncertainty in their behaviour and hence can only be properly described using a systems approach, rather than the mechanistic metaphor. Popper goes on to argue that human uncertainty results from “trial-and-error elimination” which is a result of the evolution of the human capacity for language and, consequently, humans have evolved the capacity for “critical thought”. Consequently, this leads to an epistemological representation that World One, World Two, and World Three can be considered to be a conscious, dynamic system in which physical, mental and social phenomena can be explored critically.

The essential point from all of this is that engineering practice has been extraordinarily successful in its utilisation of what has been largely a positivist, mechanistic view of the world (albeit recognizing and accepting that systems analysis is a powerful technique for predicting the response of and for control of complex systems). That is, the practice of engineering has largely been confined to the physical world, or World One and World Three representations of it. But this paradigm is not sufficiently rich to engage in the Type 3 problems of sustainability and sustainable development. The point to be emphasised here is that a practical philosophy of engineering must recognise that indeterminacy and error are not merely due to model inaccuracy, rather they are a fundamental characteristic of the way the world is. A challenge for the way in which these Type 3 problems are to be structured is to identify a way to represent problem information so that it makes clear the holistic, systemic nature of the problem across all its dimensions. Furthermore, the system paradigm presented here is not limited to World One phenomena, but rather extends to broader World Three and World Two influences. Hence, for engineering to be relevant and fully engaged in providing solutions to Type 3 problems, a practical engineering philosophy must be built on a broader view of the world which recognises World One, World Two, and World Three interactions and influences, and encourages critical thought as the predominant means of identifying problems solutions.

One of the challenges in creating such a philosophical framework is what appears to be two quite different positions in relation to concepts of truth adopted by those who have traditionally followed the scientific approach compared to adherents of critical theory and social theory. It is important to have some understanding of these positions if a critical philosophical framework is to be developed. Thus, the next section will briefly describe these two positions, arguing that both approaches are appropriate, depending on the aspect of the problem being considered.

4.5.1.3 Consideration of the nature of truth
At the heart of consideration Type 3 problems, is the need to reach some agreement on whether or not problem information or the discourse resulting from its consideration is true, that is to say, that it is an accurate representation of the problem situation. It is beyond the scope of this dissertation to enter into a lengthy discourse on truth, rather, the position adopted here simply will be stated and the rationale given as to why such a stance has been taken.

In most considerations of truth, attention is given to two questions: what is the nature of truth, that is, what is meant by the term “truth” (or, more specifically, what is the meaning of the truth predicate63) and what are the criteria for determining whether or not something is true. Although some mention will be made here relating to the nature of truth, the main focus is consideration of the second question, the criteria whereby one can determine whether or not something is true.

The concept of truth only has relevance in the context of the communication between self-conscious, linguistic beings, as these are the only beings capable of understanding and using concepts of truth and falsity. So here, truth will be considered as a concept essential to human communication and understanding. Theoretical approaches to what is meant by “truth” fall into two broad groups. On one hand, there are those which consider truth to be some genuine property of, or relation involving, propositions, that is, the content of assertions or beliefs – these are substantive approaches. And, on the other,

63 The “truth predicate” is a form of words x “is true”, x being the place where a term may be introduced to which the predicate legitimately applies. The nature of x is contentious: some argue that propositions, the contents of belief-states, and the meanings of asserted sentences are the primary “truth-bearers”, whereas others deny the existence of propositions, arguing that the primary truth-bearers the belief-states and the asserted sentences themselves.
there are those which deny this, arguing that the property or relation of truth does not exist and that we should not be misled by the similarity of the truth predicate “is true” to other predicates (such as, for example, “is red”) into thinking that similarly it denotes something real. In other words, it is wrong to interpret the truth predicate as representing a genuine property (truth) of a thing, proposition, or belief in the same way as redness might be considered to be a property – these are so-called deflationary approaches (Lowe (1995), Schmitt (2004b)). These deflationary approaches propose that the truth predicate exists to fulfil a purely linguistic function enabling speakers to do certain things, such as express agreement with one another.

Two influential theoretical approaches to truth, which have been considered extensively in the 20th century, are the correspondence approach and the coherence approach and these will be contrasted here. Both are substantive approaches in that both hold that such a thing as truth exists and that it is a property of, or a relation involving a “truth-bearer” (that is, a proposition, sentence, or belief-state) and a theoretical, omniscient “cogniser”. Correspondence approaches propose that truth is correspondence with “the way the world is” and is independent from the cogniser, whereas coherence approaches argue that truth is coherence between truth-bearers and includes the relationship between the truth-bearer and the ideal cogniser64 (Schmitt (2004c)). Correspondence theories have their origins in Greek philosophy whereas coherence theories are more modern, emerging in the late 19th and early 20th centuries.

Another distinction which can be made regarding theories about the nature of truth is that between linguistically- and epistemically-oriented approaches. Modern linguistically-oriented approaches attempt to use analysis of the meaning of words and grammar to logically identify and describe the nature of truth and were used extensively to argue for correspondence approaches. On the other hand, epistemic approaches argue that the linguistic approaches perpetuate a weakness of the traditional correspondence theory (namely, that truth is a relationship – correspondence – between a truth-bearer and some piece of reality) and hence fail to give an account of truth which allows us to understand how the notion of truth contributes to our efforts to know and, to this extent, give an inadequate account of truth.

64 Popper (1972b) stated the correspondence theory as: “a statement is true if and only if it corresponds to the facts”, whereas the coherence theory may be stated as: “a statement is true if it is coherent with other beliefs that we hold”.

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The linguistic approach became influential with the analytical philosophy of Russell and Wittgenstein in the early 20th century and was at its most influential with the logical positivists’ interpretation (in particular, the semantic treatment by Tarski) of the “correspondence theory of truth” in the 1930s (Davidson (1990)). There have been two major epistemic approaches to truth, both of which have their origins in Spinoza, Hegel and other traditional philosophers. These are the pragmatist theory of truth, proposed by C.S. Peirce, James, and Dewey in the late 19th century (Haack (1976)) and the coherence theory of truth, heavily influenced by the British idealist Bradley in the early 20th century (Schmitt (2004a)). The coherence theory of truth has been the more influential, particularly within the decision sciences.

In the discussion below, first the importance and nature of truth will be examined briefly, followed by some discussion of the correspondence and coherence approaches but considering them primarily in the specific context of providing criteria for truth, rather than a broader examination of their usefulness in determining the nature of truth.

4.5.1.3.1 The Importance of the nature of truth in dealing with Type 3 problems
As noted earlier, the fundamental ontological basis of the critical, practical engineering philosophical principles being developed here is that there is a real world independent of the human mind. If we are to be able to relate to the real world, we need a means to accurately represent our theories, concepts, and models of real-world phenomena and to develop a means of communicating these representations with each other. Hence, the answer to the first question as to the nature of truth is that a realist ontology requires truth to be conceived of correspondence-theoretically. That is, a realist ontology requires a correspondence-based approach to truth. It is important to note that this conclusion is not based on the claim that acceptance of realism entails the correspondence theory of truth. Rather, the assertion made here is that if a real world independent of human thought exists, human thought needs a way to form accurate representations which in some way correspond to these independent real-world phenomena. Nor is this to argue that the correspondence theory of truth as commonly formulated is a satisfactory means of providing such a correspondence-based approach. Indeed, in a notable exchange between Austin and Strawson in 1950, (Austin (1950), Strawson (1950)), the generally accepted view is that Strawson largely dismissed the commonly articulated correspondence theory of truth as a means for understanding the meaning of truth,
demonstrating that the argument was circular (Hamlyn (1962), Sainsbury (1998), Searle (1995b)). However, Strawson did not deal with the usefulness of the correspondence theory as a criterion for determining truth.

The discussion will now turn to consideration of criteria for truth which provide the means to interpret things and phenomena in all three Worlds.

4.5.1.3.2 Criteria for truth
4.5.1.3.2.1 The Correspondence Theory
The correspondence theory of truth, as commonly formulated, is a linguistic approach and has been used to address both the question of the nature of truth and as the means to determine whether or not something is true, that is criteria of truth. As noted above, the commonly articulated correspondence theory is inadequate as an account of the nature of truth\(^\text{65}\). However, if it is framed in linguistic terms, the concept of correspondence can provide the means for determining whether or not something is true (Hamlyn (1962), Searle (1995b))\(^\text{66}\). Thus the correspondence criterion of truth – that is, a correspondence theory for testing truth – provides an important means for linguistically testing our representations of objects and phenomena in the real world. That is, it provides the means to determine whether or not our understanding of World One phenomena is accurate.

4.5.1.3.2.2 Coherence approaches to truth
As noted above, the coherence theory has been influential in the decision sciences, particularly in the provision of social planning and is becoming a widespread influence in the sustainability discourse. Of particular importance was the concept of coherence proposed by the British idealist, Bradley (Davidson (1990)). The argument put by Bradley (Bradley (1909b), Bradley (1909a)) was that because of the fallibility of

\(^{65}\) notwithstanding the assertion here that the nature of truth ultimately must be dealt with correspondence-theoretically.

\(^{66}\) Briefly, Searle’s argument is this: “true” is an adjective used for assessing the trustworthiness of statements representing things as they are in the world. The disquotation approach (“S” is true if and only if it corresponds to S) represents a criterion of reliability – whether or not statements are true is determined by how things are in the real world and is independent of the statement itself. The term “fact” names those independent things in the real world and because, as Searle puts it, “statements determine their own truth conditions” and because facts are those things which make statements true, the way to specify a fact is the same as the way for specifying a statement and requires a whole clause. This means that although the structure of “the fact that...” and “the statement that...” are specified in the same way, this does not make facts linguistic. Facts and true statements are different because the relationship may be one-to-many, with the same fact being able to be stated by many different statements.
perception and memory, representations cannot be free of error and that conceptions of truth must be formed within the context of a systematic whole. More recently, coherence was further developed as a criterion of truth by Rescher (1974). He contrasts the Euclidean model of the hierarchical acquiring of knowledge, based on axiom, theorem, and deduction, with a “network model” in which knowledge and theses are interconnected and such connections are determined not only by deduction but also by inference. The important point here is that coherence approaches reflect the Hegelian concept of “wholeness” and “system”.

As Niiniluoto (1999d) notes, epistemic approaches (of which the coherence approaches is an important instance), appear to have been motivated by the “classical definition” of propositional knowledge as “justified true belief” – if we believe in a particular proposition and have some justification for it, our knowledge is strengthened and we are justified in believing it. There are two problems with the justified true belief model and thereby with the epistemic approaches that are based upon it. First, if the infallibilist position is rejected (because of the possibility that perception may be mistaken), knowledge becomes nothing more than justified belief, rather than justified true belief. Because beliefs may be influenced by cultural norms and values which may or may not be true, true knowledge cannot be distinguished from untrue knowledge based on justified beliefs alone. But it may be that many of our beliefs evolve because they are true and not relative to prevailing norms and cultural standards per se. It may also be that some beliefs and norms change because we discover them to be false and in need of revision. The justified true belief model contains no reference to either possibility, hence it cannot help us understand how we can evolve towards true knowledge. Furthermore, there is the problem that epistemic approaches to truth seem to limit what is true to that which is or can be known by humans. This seems absurd for surely there are many true things which humans never can or never will discover.

67 Niiniluoto formulates this concisely as: X knows that b if and only if (a) X believes that b; (b) b is true; (c) X has justification for b. The infallibilist argues that if the justification in (c) is strong, (b) implies that the truth of b can be determined with certainty, whereas the sceptic argues that because perception may be mistaken, no knowledge is possible. Between these two positions, are various forms of fallibilism which argue that our only hope for accessing truth is via “justified beliefs” – if (a) and (c) are successful, we have strengthened the assertion in (b).
4.5.1.3.2.3 Using both Correspondence and Coherence criteria for truth

Given these difficulties with epistemic approaches generally, the question arises as to when epistemic approaches and, in particular, the coherence theory might be useful. Historically, the correspondence and coherence approaches are often placed in opposition to one another – each is taken to preclude the other. But the two approaches are only in opposition when taken to be definitional, that is, as an explication of the concept of truth (or, more precisely, the meaning of the truth predicate). When considered specifically in the context of being criteria for truth, each can be assigned its place, depending upon the way in which the problem is defined and structured. Indeed, Popper (1972e) notes that coherence approaches can provide valuable insight into problem situations, even though they cannot provide sufficient justification to determine truth. If the aim is primarily one of developing and extending our knowledge, focusing on and resolving points of difference between theoretical approaches is entirely appropriate, so it is reasonable to contrast correspondence with coherence to better conceptualise and understand the truth predicate. However, if the aim is one of practical reason – to use philosophy as a means to inform the way in which we should act – the emphasis should be on common ground rather than points of difference. This is not to say that points of difference should be ignored, rather that commonly accepted and agreed knowledge should be used to guide our actions. Hence, it is argued here that both coherence and correspondence approaches should be used criteriologically, in particular using coherence approaches to inductively inform our understanding and application of correspondence-based criteria.

In summary, the important point is this. The coherence approach (in its criteriological sense) is useful as a criterion of truth for beliefs, statements, or theories about things which are subjectively determined, that is, about norms, values, morals, ethics, aesthetics and so on. But there are some beliefs, statements, and theories about things where the aim of inquiry is for them to be objectively determined (for example, mathematics, quantum mechanics, astrophysics, chemistry, and biology) and should be considered correspondence-theoretically. And, as noted above, the correspondence approach provides the means for determining whether or not our understanding of real-world phenomena is true\(^68\). Hence, in structuring the Type 3 problem, it is important to establish

\(^{68}\) It is tempting to suggest that correspondence criteria should be used for World One and World Three phenomena and coherence criteria for World Two phenomena. However, this does not take into account that World One phenomena can only ever be interpreted subjectively through our World Two representations and that certain World Three phenomena, such as theories of morality, ethics, and aesthetics are determined largely through cultural norms that reflect collective subjective agreement.
as much of the problem content as possible within an objective domain so that they can be tested using correspondence criteria, without compromising the need to utilise coherence criteria in relation to those things which are subjectively determined.

Traditionally, engineering practice has restricted itself largely to those domains that are intersubjectively testable – that is, their truth (or falsity) can be determined through application of correspondence criteria alone. This highlights an important limitation to traditional engineering practice in being able to deal adequately with the complexity of Type 3 problems found in the sustainability discourse, in particular, where the subjective issues of values, emotion, culture, behaviour, moral status, beauty, and so on predominate. There are two implications from this. First, in order to develop a critical, practical, philosophical approach to engineering which moves beyond the traditional paradigm and is capable of tackling Type 3 problems, there must be recognition that uncertain and conflicting beliefs, statements, and theories about World Three matters such as norms, values, and interests will emerge from among the domain of interests, and must be considered to be part of the problem. Furthermore, among those who are attempting to structure and solve the problem there also will exist conflicting beliefs, statements, and theories and these too become part of the problem. And second, consideration of these aspects of the problem in terms of correspondence criteria is inappropriate – the test of truth must be one of coherence, in particular coherence in relation to the problem-solver’s beliefs about the problem domain but also taking into account conflicting views of others within the domain of interests.

Engineering must be a key discipline in contributing to the solution of Type 3 problems but to be effective it must move beyond the traditional, positivist paradigm. Critical engineering practice must come to recognise the influence not only of conflicting beliefs, statements, and theories represented within the broad domain of interests but also must recognise that the engineer cannot be a detached, independent bystander and that attempts to structure and solve the problem themselves become part of the problem.

### 4.6 Principles for a practical philosophy of engineering

The point has now been reached where a set of practical philosophical principles for engineering can be stated concisely. These are:
Chapter 4 – Towards a Practical Philosophy of Engineering…

P1. There is a physical world which consists of mind-independent things;

P2. There is a mental or psychological world which is an emergent, human phenomenon with which the human mind represents its perceptions of the physical world;

P3. In a physical sense, there is an infinitely complex parade of events and phenomena located in space and time – this is “the way the world is”;

P4. The world is fundamentally indeterministic in nature and its individual parts can only be understood in relation to the whole, that is, in the context of the “system”;

P5. Although it is beyond the capacity of the human mind to understand completely and to describe adequately the way the world is, the human mind forms linguistic and other representations, based on perception and thought, which attempt to arrive at some “true” (but incomplete) understanding of the way the world is;

P6. “Truth”, a human phenomenon, may be considered from two perspectives. One is an objective “fact of the matter” which relates to physical phenomena and objective representations of the real world and these representations can be determined to be either true or false. The other is a subjective representation of socially-determined phenomena and the truth or falsity of these representations is determined linguistically, according to generally accepted and verified beliefs and values. In both cases, the appropriate position to take is to acknowledge them as being true (or false), subject to the ever-present possibility of error and the context in which their truth (or falsity) is determined. Both correspondence and coherence approaches to truth each have their place but only as criteria for determining truth.

This framework draws heavily on the philosophy of Popper (1972c) and Niiniluoto (1999a) but also recognises the social influences identified by Kuhn (1962), Feyerabend (1975c), and Lakatos (1978). While it acknowledges some aspects of Putnam (1977)
concept of internal realism, it is more closely aligned with the notion of external realism of Searle (1995a) and also, to some degree, the critical realism of Bhaskar (1998), criticised by Chalmers (1988). Of interest was the contrast between Popper and Habermas by Mingers and Brocklesby (1997), Mingers (2001), and Midgley (1996) and, most particularly, the extensive analysis of the two theoretical approaches by Ulrich Ulrich (1983e), Ulrich (1983f).

4.7 Practical application of the principles
In practical terms, how might the principles outlined in this chapter be applied, particularly in the context of the Type 3 problem of the sustainability discourse?

The contention made here is that the most appropriate way for these principles to be utilised is through problem definition and, in particular, problem-structuring. In broad terms, it is suggested that problems be structured in such a way as to recognise World One, World Two, and World Three aspects of the problem but accepting that a purely reductionist approach is not appropriate. That is, Type 3 problems should be considered as dynamic systems with World One, World Two, and World Three system components and subsystems. For those aspects of the problem which relate primarily to World One phenomena and their World Three representations (such as material things, physical events, physical processes, and the analysis and theories which describe them), a Popperian critical-rationalist approach, using truth criteria which are primarily correspondence-based is the most appropriate. For those aspects of the problem which have their origins in World Two and World Three phenomena and their World Three representations (such as beliefs, feelings, emotions, ethics, moral issues, and social phenomena), a Habermasian critical-theory approach, using truth criteria which are primarily coherence-based should be preferred. One consistent theme of this dissertation is that to take a purely reductionist approach to problem-solving is not a satisfactory means by which to come to terms with Type 3 problems. But because of the cognitive limitations which naturally prevent human understanding of Type 3 problems in their entirety, some reductionism is necessary to form a workable representation of the problem in question. The important point is to recognise that such an approach can only ever yield an approximate representation of the system as a whole.
As noted early in this chapter, engineering practice has largely been instrumentalist and as such has been most successful in addressing those problems which respond well to the reductionist approach. Engineers often see their profession as understanding a wide range of natural phenomena, using existing scientific paradigms to utilise, alter, or control the environment in order to provide some advantage to mankind. In much the same way as the original empiricist notion of a scientist being an objective, independent observer of an experimental situation, so too do many engineers see their role as providing an objective, independent solution to some technological problem. At the heart of the argument presented here is that this philosophical position is both dated and inappropriate for certain types of problem – in particular, the Type 3 problem. The notion of the detached, independent practitioner actually prevents the gaining of a holistic understanding of the Type 3 problem. There must be recognition that the engineer is an integral part of the system and influences the system response to external disturbances.69

What is proposed here is that there be a “Copernican revolution” in engineering practice. Copernicus made a paradigm shift in realising that the earth revolves around the sun and Kant identified a Copernican revolution in philosophy through his insight that, rather than assuming knowledge must conform to reality, actually we identify knowledge to which our conceptions of reality must conform. So too must engineers change the prevailing paradigm for engineering practice. In order to engage completely in Type 3 problems, engineers must see themselves as a part of the problem and the environment in which the problem exists, not separate from it. Rather than being the detached, independent provider of a solution which is imposed upon the problem, the engineer’s role needs to be one of an informed representative of the moral interests within the problem domain. The engineer must seek to provide a rational, critically-derived solution, which includes consideration of the physical, the subjective, and the objective elements of the problem and must propose a set of morally-acceptable, potential solutions, implementing the one with the “best” outcome. The Type 3 problems of the sustainability discourse require such solutions to be identified and implemented – the problems exist because their importance has been identified and it is acknowledged widely that solutions must be found. To do nothing is not an option.

69 Considering the “engineer as a citizen” part of the system, affecting system dynamics distinguishes this position from the “honest broker” role (mentioned in footnote 56 of this chapter), which suggests that the engineer is a go-between or intermediary, rather than being directly involved in the system. That is, the honest broker conception appears to persist with the positivist, independent role of the engineer which has largely been rejected in the philosophy of science discourse of the last 70 years or so.
In practical terms, engineers must acknowledge their function as socio-political influences in the problem context, recognizing their privileged position within the system (in the sense that their education and professional expertise happens to give them specific technological insights into the way in which certain aspects of the system may respond) and take a leadership role in coming to terms with the broader political and societal issues. Such a position is almost totally at odds with much current engineering practice – the practical philosophical principles espoused here represent a new paradigm which, rather than seeking detached independence and objectivity, actually requires engagement in the problem not only as engineers but as citizens.

The remainder of this dissertation will develop a problem-structuring approach which is consistent with such a paradigm shift.

4.8 References


Chapter 5: Cognition, Judgement, and Decision-Making in Uncertainty

5.1 Overview and introduction

The brief history of the emergence of concerns regarding sustainability and sustainable development outlined in Chapter 2 suggests that there has been a significant change in the type of problem exposed by modern development. Not only are problems no longer localised, having regional or even global impact, but they reflect deeply held philosophical positions and moral issues among the domain of interests, some of which may be irreconcilable. In Chapter 3, problem complexity was considered in greater depth and the complex problems of sustainability and sustainable development were identified as instances of a broader problem typology: the Type 3 problem. The Type 3 problem situation was identified as having many dimensions, both in terms of the problem itself and also the domain of interests involved in problem articulation and resolution. Not only are there overwhelming amounts of information which are interrelated and interact in a systemic way, but the decision-making domain can be a major determinant of whether or not problems are even recognised and accepted, let alone resolved.

A qualitative change in the nature of the problem situation has been identified as these problems emerged, showing that the challenge the decision-making domain faces is not simply coming to terms with a highly complex technological system, but rather a system with many dimensions: technological, moral, social, economic, environmental, philosophical, psychological and so on. In Chapter 4, it was pointed out that the traditional, analytical, reductionist approach, which has been the mainstay of engineering practice for the best part of 200 years, is inadequate to deal with problem situations of this type. As a starting point for further consideration of how these problem situations might be addressed, the discussion in Chapter 4 pointed some philosophical deficiencies of current engineering practice and proposed a set of principles that might form the basis for sustainable engineering practice in the 21st century. But the cognitive challenges identified in Chapter 3 remain.

The proposition to be developed in this chapter is that, in order to come to terms with the highly complex Type 3 problem, structuring the problem information is important. Such a problem structure must be consistent with the set of philosophical principles
developed in Chapter 4 and must align with the way in which human cognitive processes are thought to work, in particular, the way in which people are thought to form judgements, make choices, and reach decisions in situations of uncertainty. Such a problem-structuring approach will facilitate engagement with the problem-solving domain, thereby enabling it to better come to terms with the complexity of the problem situation. At the very least, a transparent exposition of the philosophical principles and psychological theory upon which the problem is structured will, itself, encourage and facilitate critique. The problem-structuring approach to be developed in Chapter 6 will be framed around these philosophical principles and the theoretical cognitive approach to be developed in this chapter.

As discussed in Chapter 4, Popper conceived of three distinct ontological entities: World One, the world of physical reality; World Two, our subjective knowledge or knowings; and World Three, our objective knowledge. The world of physical reality is immensely complex and it is far beyond the capacity of human cognition to understand it completely. If the optimistic position relating to human cognition is taken (Jungermann (1983)), the human mind has evolved to be able to form representations of the real world, which simplify considerably our perceptions of it, thereby enabling us to come to terms with this complexity within our cognitive constraints. These mental representations are formed, organised, and utilised in ways which allow us to form judgements, make choices, and reach decisions under uncertainty.

There is a large body of work in cognitive psychology directed at understanding the way these mental processes work, the way in which the representations of the real world are dealt with in human thought processes, and how these function in terms of judgement, choice, and decision-making. It is beyond the scope of this dissertation to consider this body of work in depth – rather, some particular aspects of human cognition will be discussed, in order to provide a theoretical basis upon which to develop the problem-structuring approach. At first glance, this might appear to be an ambitious task but the aim here is not to formulate a new theory of decision-making or even to justify or rationalise existing theories. Rather, it is to propose a reasonable framework to guide the representation of problem information, which is likely to be coherent with the way in which human thought processes work. This would reasonably be expected to facilitate greater engagement of the decision-making domain in identification of and ultimately the
resolution of the problem situation. This is important because a fundamental aim of this dissertation is to develop a robust, practical problem-structuring approach with which to attack the Type 3 problems of the sustainability discourse. To distinguish this from practical approaches which have evolved largely by trial-and-error and adopting approaches which seem to work, the intention here is to ground the problem-structuring approach on clear, practical philosophical principles (as developed in Chapter 4) and then to build the approach on two important areas of theory: established cognitive theory and general systems theory – see Chapter 6, section 6.3.4.

This chapter is structured in two parts. First, consideration will be given to uncertainty: the nature of uncertainty itself and the way in which humans are thought to deal with it, including constraints and biases, which human exhibit in forming judgements, making choices, and reaching decisions in an enormously complex and uncertain world. The conclusion from this part of the chapter is that, in order to more effectively come to terms with this complexity and uncertainty, structuring problem information in a way which aligns with established, theoretically-described cognitive processes is an important step which must be taken before formal decision analysis techniques can be utilised. The second part of the chapter, referring to this established body of cognitive theory, develops the means to form mental representations of problem information. That is, a theoretical, psychological basis will be established for the development of the problem-structuring approach to be explicated in Chapter 6.

This second part of the chapter will cover these five subjects:

1. a brief description will be given to the way in which real world things and phenomena appear to be represented in human thought processes;
2. consideration will be given to a theory as to how these mental representations are actually formed in the human mind;
3. a second-generation behavioural decision-making theory will be discussed as a plausible means for explaining the way in which people embark upon decision-making in uncertainty;
4. the use of maps and cognitive mapping will be discussed, exploring their usefulness as a means of both linguistic and pictorial representation of problem information; and
5. Consideration will be given to how narratives and scenarios can be used to develop a cognitive framework.

Taken together, these provide a framework analogous to the means humans apparently use to form mental representations of problem information in all four dimensions of the real world (the three spatial dimensions and the temporal dimension). These form the cognitive framework around which the problem-structuring approach is to be developed in Chapter 6, with the principles of sustainable engineering practice outlined in Chapter 4 providing the underlying philosophical foundation.

5.2 Dealing with uncertainty
5.2.1 The nature of uncertainty and human cognitive responses
In any given problem situation, uncertainty derives from three fundamental sources. In the first place, there is uncertainty arising from indeterminism in the physical world itself. This derives from the randomness of events in nature, particularly from the disorder within the boundaries of the problem system under consideration and the progression of phenomena in time. Then, there is the uncertainty associated with the individual’s internal representations or understanding of the real world phenomena and the events which it encounters. The extent to which this is important relates both to the cognitive capacity of the individual, and to the complexity of the problem situation. There are influences from perceptions of the real world but these are mediated by the individual’s cognitive framework, including beliefs and values. And third, is the uncertainty associated with objective representations of the real world, that is, the uncertainty in the objective knowledge representing the problem situation. This includes the uncertainty from imperfections in representations of the problem situation and also the uncertainty which derives from human exchanges such as culture and social interaction. In other words, uncertainty derives from all three Worlds.

The way in which humans deal with uncertainty is cognitively - through judgement. Judgement is the process whereby the individual applies its knowledge to the problem situation, including the seeking of further knowledge and understanding (Hammond (1996a)), in an attempt to reduce the uncertainty to some acceptable level. But in each problem situation, ultimately there is a level of “irreducible” uncertainty, that is, the residual uncertainty which remains at the point at which a decision needs to be made.
(Hammond refers to this as conditional indeterminism). The irreducible uncertainty in a given problem situation originates in all three sources – physical indeterminacy and deficiencies in both subjective and objective knowledge – and must be dealt with through cognitive processes.

All conscious, thinking animals need to make sense of the uncertainty in the situations they encounter in the world, and must attempt to control it. The cognitive process they utilise is to form mental representations of the world and the phenomena they encounter, based on the information they receive through their senses; they then react and behave accordingly (Polanyi (1957)). As Epstein (1994) puts it, they form a theory of reality – a world theory – by which they relate their own existence to the real-world phenomena they encounter. This form of cognition is intuitive. In humans, intuitive thought is experiential: it relies heavily on visual insight and the recognition of patterns which appear to emerge from complex systems. It is oriented toward immediate action and it leads to the formation of representations which are persistent and slow to change. Intuition is experienced both passively and subconsciously and is affected by emotion. Epstein notes that judgements arising from intuition are compelling, bringing with them a feeling of certainty and infallibility – they appear to be self-evident. Intuitive cognition is often thought of as being imaginative, creative, and sometimes, even mysterious (Hammond (1996b)). But humans have also developed a second form of thought which is rational and analytical in nature.

This analytical form of cognition is logical, and derives from conscious understanding and appraisal of real-world phenomena in the context of the individual’s own thoughts. This form of cognition is slower to process but can change rapidly. It exists in the abstract and is denoted through language and other symbols, such as numbers. Analytical cognition is active and conscious – the individual controls its own thoughts and provides the capacity for self-awareness and to be self-reflective. Analytical cognition is based on justification which is evidential and logical (even if such logic might be flawed) and, importantly, analytical argument is retraceable. Epstein (1994) refers to this human analytical capacity as the “self theory” – the complete theory of reality for a human is a self theory with a complementary world theory, the two being interconnected by various propositions.
Such a concept of a bimodal system of cognition is by no means new. The ancient Greek philosophers distinguished between scientific knowledge and intuition (Aristotle (350BCE)), as did early philosophers of the modern era, for example, Pascal (1660) in noting the difference between the mathematical and the intuitive mind. More recently various versions of a bimodal system of cognition have been developed, for example, Polanyi (1957) (problem-solving/heuristic), Simon (1983) (bounded rationality/intuitive rationality), Tversky and Kahneman (1983), (extensional/intuitive), Bruner (1991) (narrative/propositional), Hammond (1996b) (analytical/intuitive) to name but some. Hammond (1996c) suggests that these have generally been seen as dichotomous, rather than complementary and proposes a “cognitive continuum”, which recognises the importance of both forms of cognition and that by considering the two in this way gives a much greater insight into the “commonsense” nature of human thought. Whether or not this is so is less important than acknowledging that both forms of cognition have evolved in humans and together have made the human species particularly successful. In humans, cognitive success lies in recognizing the strengths and defects of both approaches and utilising them in such a way as to benefit from the insight and creativity which derives from intuitive thought, while also recognizing power of analytical thought in bringing rigorous criticism to both our subjective and objective knowledge.

In Chapter 3, mention was made of the work done since the 1950s on decision-making competence. The work of Tversky and Kahneman was particularly influential (for example, Tversky and Kahneman (1974), Tversky and Kahneman (1986), Kahneman and Tversky (1984)) which identified a number of areas where humans appear to show consistent decision-making bias. In the first of these papers, Tversky and Kahneman found that both layman and experienced practitioners were subject to these biases “when they think intuitively”. Furthermore, they noted that “the inherently subjective nature of probability has led many students to believe that coherence, or internal consistency, is the only valid criterion by which judged probability should be evaluated”. They go on to say, “for judged probabilities to be considered adequate, or rational, internal consistency is not enough. The judgements must be compatible with the entire web of beliefs held by the individual ... the rational judge ... will attempt to make his probability judgements compatible with his knowledge about the subject matter, the laws of probability, and his own judgemental heuristics and biases” (Tversky and Kahneman (1974) p1130).
What Tversky and Kahneman referred to as “heuristics” are biases introduced through the application of intuitive rather than analytical judgement. Further work was done in a number of areas of professional practice (also referred to in Chapter 3), confirming the existence of bias in intuitive thinking (for example, finance (Slovic (1972)), the judicial system (Carroll (1978)), medical diagnosis and choice of treatment (McNeil et al. (1982)), clinical diagnosis (Arkes (1981), Kleinmuntz (1984)), and public policy decision-making (Thaler (1983)). This has led to a particularly pessimistic view regarding human judgement – that it is irrational and untrustworthy. But many of these researchers appear to have overlooked the caveat noted above, which Tversky and Kahneman (and others, for example, Arkes (1981)) identified – bias is primarily a problem with intuitive judgement, not with rational judgement.

Indeed, a comprehensive review of decision-making errors presented by Fraser et al. (1992) suggests that by understanding the source of bias, often it can be removed from the problem situation. For example, bias due to the practitioner not understanding the problem adequately, erroneous assumptions regarding problem data (such as probability data), differences in assumptions between the practitioner and the observer, can give the appearance of bias where, upon closer examination, none exists. More specifically, Nisbett et al. (1987) demonstrated that training in inference enhances rational thinking; Gigerenzer et al. (1991) showed that when carefully analysed, some biases actually did not contravene probability theory; Lopes (1991) argues that with more rigorous application of methodology, some biases are reduced or disappear; and Payne et al. (1988) shows that human decision-making behaviour shows considerable flexibility rather than being necessarily thought of as being constrained by certain types of bias.

But there is another important issue which emerges from this work on the rationality of human decision-making. Examples from law, medicine, science, and engineering show that where intuition encroaches upon the domain were analysis is required, the application of intuition can lead to blindly over-confident judgements and decisions (Hammond (1996) p106). But to set aside the value of intuitive thought on the basis of this would be to overlook the great benefit which derives from the creativity and insight of intuition across all aspects of human creativity, from mathematics and science, to the arts and humanities. A more optimistic interpretation of the relationship between intuition and analysis is that in specific instances, people may appear irrational but are
less so in the context of the entire problem situation; and that bias can be reduced if appropriate steps are taken, such as training the individual and appropriate selection of analytical methodologies.

Given the success of the human species, a more convincing argument is that a combination of analytical and intuitive cognition provides an effective way in which the individual can come to terms with the immense complexity of many problem situations. Indeed, as Simon and Newell (1958), Newell and Simon (1976) point out, there is a large class of “ill-structured” problems which do not yield to the pure, algorithmic analysis and that a “heuristic” or intuitive problem-solving approach is required. The important point is, as Simon (1983) notes, that real wisdom and expertise is the result of the balance between analysis and intuition – Simon refers to this as “intuitive rationality” – gained through many years of diligent application to a class of problems, in which the individual develops the capacity to recognise a large number of patterns or “friends”, which form the foundation of wise judgement. In other words, as can be inferred from Pascal, intuition and analysis are complementary and are needed for us to deal with the immense complexity of the real world. Our success (or otherwise) in dealing with the complexity of the real world – in particular Type 3 problems – relies on the wisdom with which analytical and intuitive processes are utilised and integrated. However, just identifying the differences between the two schools of thinking regarding the influence of bias on analytical and intuitive cognition, and observing that both have contributed to the success of the human species is not enough. Consideration needs to be given to what makes judgement and decision-making ultimately successful.

5.2.2 Forming judgements, making choices, and reaching decisions in uncertainty

In determining whether or not a judgement, a choice, or a decision is likely to be successful there are two essential questions to consider. First: is the judgement rational within the prevailing paradigm? and second: is the judgement accurate? Indeed, both are necessary for a sound judgement to be reached but neither is sufficient. For example, a rationally determined judgement may not be accurate because the prevailing paradigm

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70 This concept is at the heart of Simon’s theory of bounded rationality which was foundational in the development of first-generational behavioural theory. Because of the cognitive limitations of the human mind, a truly rational decision can never be made – the mind simply those not have the capacity to evaluate all possible alternatives. In practice, only a relatively few possibilities can be brought to mind and that ultimately all judgement and all decision-making has a heuristic, that is intuitive, component.
upon which it was determined is wrong or because of uncertainty in the problem situation. And a judgement reached based on irrational thinking (or formed from within a wrong paradigm) may yet be accurate purely by chance. In other words, for a judgement to be ultimately successful, first, it needs to be determined using a process which is coherent within the context of its paradigm, and second, the content of the judgement needs to correspond to the observed phenomena to which the judgement relates, as proposed in the philosophical principles outlined in Chapter 4.

Hastie and Rasinski (1988), and Hammond (1996d) (Hammond (2000), Hammond (2007)) argue that the two theories of truth, namely, the coherence theory and the correspondence theory, briefly explored in Chapter 4, have largely guided the development of behavioural psychology in the last 60 years. One stream of research, building on the work initially proposed around subjective expected utility by Edwards (1954a), Edwards (1955) explored whether decision-making was rational, in that it is coherent with outcomes predicted from rationally established, normative rules. The second stream, emerging from the work of Brunswik (1949), and Hammond (1955), explored whether subjects reach judgements and make decisions which are accurate, that is they whether correspond to the phenomena to which they refer. Hammond (2007) (page xxiv) acknowledges some apprehension in using the terms “correspondence” and “coherence” in relation to the psychology of judgement and decision-making and recognises that some philosophers will find his treatment contentious. However, the position taken here is that Hammond’s approach (and similarly that of Hastie and Rasinski (1988)) is reasonable if clearly limited to the context outlined in Chapter 4, that is, only using both the correspondence and coherence approaches to truth as criteria for truth and not in any definitional sense regarding the explication of the nature of truth. Indeed, strictly limiting the context in this way can lead to insight into the decision-making process used by the domain of interests, in that it can illuminate the distinction between various types of rationality. For example, has a judgement been formed through a rational determination, which is coherent with observed facts and phenomena? and is it coherent with the accepted understanding of the problem situation, which itself has been derived from rigorous analysis? Or, is the judgement derived from or influenced by underlying beliefs and values? Ultimately, sound judgement needs to be coherent both with observed facts and phenomena. That is, it must be coherent with our best understanding and objective representations of the way the world works, specific to the
context of the problem situation, and framed within a system of beliefs and values, which minimises reliance upon dogma and inexplicable belief. The problem-structuring approach, which is developed in Chapter 6, provides a means to examine these issues, so as to structure problem information. This has particular application in the development of values and objectives hierarchies for established multi-criteria decision-making approaches.

There is further insight to be gained by considering these issues in the context of Popper’s Three Worlds. As Björkman (1984) points out, the stream of behavioural psychology which examines whether or not the subject reaches a rational judgement, in relation to some normative rule (what Hammond refers to as the coherence approach), is exploring the response of the subject (which is within World Two) in comparison to an objectively determined norm (which is within World Three). The inference drawn is that the World Three norm generalises to World One phenomena and that in certain circumstances, intuitive judgement is flawed in relation to the World One phenomenon. However, all that can really be said is that the intuitive judgement of the subject is flawed in relation to the World Three norm. Behavioural studies which present subjects with physical rather than intellectual puzzles (Hammond’s correspondence approach) are examining responses to World One phenomena directly, rather than vicariously by means of a World Three representation.

The point to conclude from this is not that one approach is right and the other wrong, but rather that the two approaches can be used to complement one another and to arrive at a deeper understanding of the nature of human judgement. That is to say, we can gain a deeper understanding of our judgements, both with respect to the World One phenomena themselves and the appropriateness of our World Three representations of them, if we make transparent our underlying assumptions of values and inexplicable belief. The problem-structuring approach developed in Chapter 6 is intended to facilitate the structuring of information to make these distinctions clear and to represent them more completely in the utilisation of decision-making tools. A further point is that recognizing these distinctions supports the notion of analysis underpinning normal science and intuition as being the stuff which leads to paradigm change (Kuhn (1962), Björkman (1984), Hammond (1996e)).
One might argue that one reason for the success of the human species has been the evolution of its capacity for analytical cognition, which can identify weaknesses in intuitive thought, thus enabling them to be corrected. Unlike intuition, all analytical cognition can, if desired, contribute to the body of objective knowledge, hence, potentially, the human capacity for analysis continues to increase. That is not to say that analytical cognition is superior to intuitive cognition \textit{per se} – ultimately all decisions are made intuitively. Real wisdom comes in recognising where intuitive thought is most appropriate and others, where analysis is necessary, and then finding the appropriate balance between the two in ultimately forming a judgement and making a decision.

Unfortunately, as Hammond (1996c) points out, a conceptual barrier has developed within behavioural psychology that suggests that intuitive and analytical cognition are dichotomous, that the two do not coexist. Hammond argues that, in part, this is due to the way in which the problem is presented to the decision-making domain. That is, presenting the problem information in one way will stimulate intuitive cognition and, if presented differently, will stimulate analytical cognition. More specifically, if information is presented pictorially, with a problem description implying significant uncertainty, judgement tends to be intuitive. On the other hand, if problem information is presented technically, statistically, or mathematically, then analytical judgement is induced. Hammond argues that for the vast majority of complex problems, the problem is placed in some middle ground where “quasirationality” rules – although there are some data, “commonsense”, “comfort levels”, and “feelings” need to be incorporated into consideration of the problem. By definition, Type 3 problems are in this category. The proposition advanced here is that, by structuring the problem using a variety of devices which are built around established cognitive theory, the problem information can be organised in a way which, on one hand, makes clear the opportunities for analysis and, on the other, makes transparent the framework of beliefs, values, interests, morals and so on, which will induce the application of intuitive judgement to the problem situation.

The remainder of this chapter will draw together the necessary pieces of theory required to develop a cognitive framework, for application in structuring Type 3 problems. The approach is intended to have application in structuring problem information for use with established multi-criteria decision-making methodologies.
Chapter 5 – Cognition, Judgement, and Decision-Making in Uncertainty…

5.3 Development of a cognitive framework to structure Type 3 problems

5.3.1 Mental representations

It is a characteristic of the human mind that it forms mental representations of perceptions of real-world phenomena and, according to Popper, this forms our World Two of subjective knowings. Furthermore, these mental representations can be processed into a body of objective knowledge (Popper’s World Three), which can be developed and communicated with other individuals.

The precise nature of these mental representations is contentious. The “atomist” approach to psychology of the early 20th century, originating in Scottish analytical philosophy, proposed the machine analogy as the way in which the mind works. On the other hand, the Gestalt psychologists on the Continent, influenced by Kantian philosophy, saw the mind as a dynamic system, which represented perception holistically rather than aggregatively (Gregory (1953)). Most cognitive psychology has focused on mental representations derived from visual stimulus and perception, and there has been considerable debate around the nature of visual images and whether they are true mental representations of knowledge. One position (Boulding (1956), Miller and Galanter (1960), Kosslyn and Pomerantz (1977), Kosslyn (1980b), Kosslyn (1980a), Kosslyn (2005)) is that propositional knowledge requires some form of image beyond the purely linguistic to express positional relationships between entities. Whereas the other (Pylyshyn (1973), Pylyshyn (2002), Pylyshyn (2003)) is that mental pictures require language to fill in the gaps and to make assertions which can be tested and critically evaluated. Both are problematic in that they derive largely from consideration of visual perception – they take no account of images formed through other sensory perception, such as hearing (Broadbent (1958)). These differences are yet to be resolved but the point to draw from this is there appears to be no single metaphor, such as the “picture-in-the-head” or “mind’s eye” which adequately describes or explains these mental representations. What is important though is that human thought relies upon mental representations which appear to consist of some form of dynamic system of depictions, non-visual patterns, and linguistic representations, which can be stored, recalled, processed, correlated and evaluated – here these will be referred to as “images” – and that it is from these World Two images that World Three objective knowledge is constructed. Importantly, it has been recognised that humans only have the capacity to retain a small number of “units of concentration” (generally considered to be from four to eight) in their minds at any one time, but that they have an extraordinary capacity to
quickly recall vast amounts of information from long-term memory for processing (Miller (1956), Simon (1969)). The next question to consider is how the human mind constructs these representations.

Two theoretical approaches, *personal construct theory* and *image theory*, have been adopted here as a means for describing, on one hand, the way in which individuals form these mental representations of these real-world phenomena and, on the other, how they approach decision-making when confronted with problems of complexity and uncertainty. Both attempt to describe and represent the way in which human cognitive processes actually work and both have an extensive body of research in their support.

### 5.3.2 Kelly’s Theory of Personal Constructs

In 1955, Kelly, having practised for many years as a clinical psychologist and academic, published his Theory of Personal Constructs, developed both from fundamental philosophical principles and from clinical observations. His intention was to propose a theory of personality which explains the behaviour of humans in the context of the world in which they live (Kelly (1955a) pp3-5). There are two important reasons why personal construct theory is put forward here: first, unlike many theoretical approaches to psychology, Kelly starts by clearly stating the philosophical assumptions underlying his theoretical approach. Although these have somewhat different origins from the philosophical framework developed in Chapter 4, they are consistent with the realist ontology, the indeterministic, systems nature of the world (which can only be understood by considering individual elements within the context of the whole), and the importance of subjective representations and individual worldviews in the interpretation of the phenomena we encounter. Second, and again unlike many psychological theories, it proposes general processes by which people make sense of the world and their part in it, rather than being some explanation of human motivation, needs, or conflicts. That is, it is a theory of *how* people construe (Fransella and Neimeyer (2005)).

#### 5.3.2.1 Philosophical basis

Kelly (1955a) (pp14-17) referred to his philosophical approach as “constructive alternativism”. This is derived from his observation of humanity’s “march through the centuries” and his view that people form their own individual interpretations of their place in the stream of events in which they are swept up. Kelly’s position of constructive
alternativism is firmly based on a realist ontology – he believed that a real physical world exists independent of the mind (Kelly (1955a) pp6, 43). He also believed that people’s thoughts are real and just as the real world is constantly changing, so, too, do people’s thoughts (Kelly (1955a) p8). Furthermore, Kelly believed in the wholeness of the universe – that the universe functions as a single unit, with all its constituent parts interacting with each other, that everything is “interlocked”, and that an important dimension is the progress of the universe in time (Kelly (1955a) p6).

Kelly considered life to consist of those creatures which are able to represent their environment and react to it. That is, a living thing is able to form representations, or to “construct” the organism’s version of reality, and that these constructs are created and modified according to their usefulness as explanations of real-world phenomena (Kelly (1955a) pp 7-8). They are “ways of construing” the world and enable man (and other sentient creatures) to chart a course of behaviour, according to the experiences they encounter and their intellectually reasoned thoughts. People attempt to improve the usefulness of their constructs both by altering them to fit with those aspects of the reality they experience, and by increasing their repertory of constructs. These construction systems can be widely shared and communicated with others, being categorised into specific fields and realms of knowledge (Kelly (1955a) pp8-12).

Now, there is an important issue to emphasise here: Kelly was not saying that in forming these constructs of reality that life is not real, nor was he saying that reality only exists as represented by the constructs. He was simply saying that because we must rely on our senses to perceive the real world and because we have no certain way of determining whether our perceptions actually correspond with the real world, there will be as many perceptions of reality as there are people. Furthermore, he argued that these mental representations are themselves real but only to the individual which forms them. For example, a person, perhaps due to illness, might misrepresent or misconstrue some aspect of reality, thus forming an inaccurate representation of it, but nonetheless to that person the perception is real (Kelly (1955a) p8). There are two essential points to note from this: first, although Kelly claimed to be an ontological monist – that is, he believed that the real world exists and that human thoughts are real and ontologically indistinguishable from the real world – he recognised that it had some pluralist characteristics. His position is consistent with Popper’s World One and World Two, (in
the sense with which Popper’s model is used in this dissertation). Furthermore, Kelly’s recognition that construction systems can be widely shared and communicated as specific realms of knowledge is suggestive of Popper’s World Three of objective knowledge. The second essential point is that, although the physical world exists independent of the mind, we can only become aware of the physical world through successive approximations as represented in our mental constructs. Kelly recognised that all assumptions of fact are subjective and alternative constructs can be formed, introducing uncertainty into our knowledge.

5.3.2.2 Theory of Personal Constructs

The fundamental postulate underlying Kelly’s theory is “a person’s processes are psychologically channelised by the way in which he anticipates events”. That is, the person is a purposeful organism, which is constantly attempting to understand its own nature and the nature of the world in which it finds itself, and which is continuously testing this understanding in order to better control its circumstances (Kelly (1955c), Bannister (1962), Bannister and Fransella (1971)). The term “channelised” refers to the

71 Kelly’s work was influenced by the American pragmatist approach of Peirce and James that truth is what remains at the end of enquiry.

72 In the operational research literature, there is a common misunderstanding of Kelly’s ontological position. For example, Midgley [Midgley, G. (2000) Systemic intervention: philosophy, methodology, and practice, New York, USA, Kluwer Academic Publishers] refers to Kelly (1955) stating that “Kelly questions the whole distinction between “knowledge” and “world”, arguing that all we can possibly have access to is knowledge. Therefore, he suggested there are as many worlds, or realities, as there are human beings. This is a radically subjectivist ontological stance that not only contrasts with realism, but also runs counter to other anti-realist thinking being developed in the 1950s, such as that proposed by Wittgenstein (1953)” – pp26-27. Midgley goes on to say (on p 37) “it should be readily apparent that Kelly’s methodology not only excludes from valid practice any exploration of the “truth”, but also outlaws method supporting the collective critique of norms. This according to Holland (1970), is an inevitable consequence of Kelly’s philosophical assumption that the individual is the primary generator of meaning”. But these interpretations are wrong. Kelly (1955) (pp6-7) clearly states “we presume that the universe is really existing and that man is gradually coming to understand it” and later, “the three prior convictions about the universe that we have emphasised in this section are that it is real and not a figment of our imaginations, but it all works together like clockwork, and that it is something that is going on all the time and not something that is merely stays put” and, so there can be no misunderstanding, “the universe is real” (p43). It is clear that Kelly’s position of “constructive alternativism” refers to his view (based on his notion of “man the scientist”) that we try to form (that is, construct) mental representations which enable us to come to terms with a complexity far beyond the capability of human cognition and that we revise these conceptions based on our experience. Kelly says “in emphasising the prior conviction that life involves the representation or construction of reality, we should not imply that life is not itself real ... any living creature, together with his perceptions, is a part of the real world; he is not merely a nearsighted bystander to the goings-on of the real world”. The important distinction Kelly makes here (p 8) is that an individual might through illness or delusion misrepresent some real phenomenon but that individual the misrepresentation may be entirely real. In other words, someone might misunderstand or be deluded regarding reality and the firmly convinced that their misrepresentation is real but that does not make it so. In short, Kelly was explicitly a realist and, implicitly, clearly accepted some notion of truth against which mental constructs could be compared but recognized that all assumptions of facts are subjective and that alternative constructs can be formed bringing considerable uncertainty into subjects such as science.
fundamental structure underlying human psychological processes – it is constantly changing but because it is structured, it both assists and constrains the individual in its choice of actions. Kelly went on to identify eleven corollaries which emerge from the fundamental postulate. These can be summed up like this.

People think inductively, particularly influenced by verbal representations of today’s experiences to anticipate tomorrow’s events, recognising that they will not be quite the same as those of today. Differences in behaviour between individuals are reflective of the differences in their subjective worlds or the way in which they construct their interpretation of events. Hence, two individuals exposed to what appears to be the same situation respond differently, because each sees the situation through the lenses of their own system of personal constructs. Not only do people form different representations of events, but they organise their system of constructs differently in terms of the subordinate and superordinate relationships between them.

The way in which people form their representations is by means of “dichotomous constructs”. Kelly argued that in order to form a construct, three representations are needed: two of these represent opposing poles of a similarity, against which the third representation is contrasted. (For example, “goodness” might be represented at its two poles by the dichotomy “good-bad”, against which something, such as an experience, might be contrasted, in order to form a construct to represent whether or not the experience was good.) People then make use of a “scalar” to represent the extent of the contrast (in the example, how good the experience was). That is not to say that bipolarity always exists or can always be readily identified, rather, Kelly suggests, it is that people contextualise their constructs as though they are bipolar.

In forming constructs, individuals choose within a finite range of events, selecting constructs which they expect to have the best anticipatory value for some future decision. They then organise and change the constructs, according to their experiences. The extent to which a person’s construct system varies depends on the degree to which it allows new elements and influences to permeate the system. Furthermore, an individual’s construct subsystems may “fragment”, in that they may change, to the extent that they become incompatible with one another over time. That is, successive re-formulations of representations, as a consequence of ongoing experience, can be
significant enough that they cannot be inferred from previous formulations. This is important because people’s views or behaviour can change significantly and may not appear to be derived from previous views or behaviour. Kelly also proposed that where two people have similar constructions of events, their psychological processes are similar and that where a person construes the construction process of another person, the first person may engage in a social process with the second, even though their constructs may not be the same. This summary of personal construct theory has been brief. For a more comprehensive treatment, see Kelly (1955c), Bannister (1962), Bannister and Fransella (1971), Kenny (1984), Fransella and Neimeyer (2005). (See also Hector et al. (2007) for a concise description of its application in a problem-structuring approach.)

As noted above, at the heart of Kelly’s theory is the way in which people form constructs for any phenomenon they want to evaluate. They first identify two extreme poles and then, by way of contrast, compare a third position with these. Kelly (1955b) and others developed a set of psychological tests generally known as “repertory grid tests”, which are used to elicit psychological constructs (Bannister (1962)). The general approach in these tests is to ask respondents to consider things of interest (such as relationships, values, behaviours, etc) within categories which are grouped in threes, with the respondent being asked to note which two are alike and which one is different. The results of these observations are then analysed statistically. Repertory grid tests have been developed in a number of different formats and applied widely across various types of problem. Most of these have been in clinical psychology but they have been extended into other areas as well (for a comprehensive, annotated bibliography of a wide range of applications of various types of repertory grid tests, see Fransella and Bannister (1977)).

In addition to clinical psychology, personal constructs theory has been used in areas relating to decision-making (for example, Murray-Prior (1998), Butt (2001), Brugha (2004)) and with specific application to the structuring of complex problems as the basis for a cognitive mapping approach, developed by Eden and others (Eden and Jones (1984), Eden (1988), Eden et al. (1992), Eden and Ackermann (2004)). In the latter application, the technique is used to represent highly complex problems diagrammatically, in order to facilitate engagement by problem stakeholders and decision-makers.
The next question to consider is how these mental representations or constructs are used to help form judgements, make choices, and reach decisions, particularly under circumstances of uncertainty. The approach to be used here is based on second-generation behavioural psychology, which emerged from decision theory as discussed in Chapter 3.

5.3.3 Another perspective on cognitive approaches to judgement, choice, and decision-making

As noted in Chapter 3, most decision theory developed since the 1950s has taken a utilitarian approach – that is, the underlying assumption is that a satisfactory outcome is represented by maximisation of utility of one form or another, being based on a gambling metaphor. But there have been a number of other approaches which have been explored and Beach and Connolly (2005b) point out that these can be grouped into four broad categories: recognition theories, narrative theories, incremental theories, and moral/ethical (or deontological) theories.

Recognition theories generally consider two aspects of the problem situation: first is interpreting events in the context of previous experience; and second, is the response elicited from the initial interpretation. Beach and Connolly (2005b) note that the advantages of recognition-based theories of decision-making are that people can identify behaviour which is familiar to them. However, these theories have the disadvantage that they are largely descriptive – they do not explore the mechanisms of the way in which decisions are reached. Three notable narrative theory approaches are scenario theory, story theory, and argument theory. Scenario theory (Jungermann (1985), Jungermann and Thüring (1988)) proposes that a plausible narrative can be developed from which forecasts can be made. There are four steps in the theory: first, the problem is framed, with relevant material from which cause and effect that relationships can be established; second, if/then propositions are developed to build a cognitive model of the situation; third, the “if” parts of the propositions are assigned values; and finally the model is run evaluating various alternatives. Story theory (Hastie and Pennington (2000), Pennington and Hastie (1986), Pennington and Hastie (1988)) has largely been based around research in jury decisions and relates to the construction of verdicts which are consistent with a story developed by each individual juror from the evidence presented. Beach and Connolly (2005b) note that both scenario theory and story theory involve constructing a cognitive model (that is, a scenario or a story); however they are different in that scenario
theory relates to decisions about the future, whereas story theory relates to decisions about the past. Beach and Connolly (2005b) also refer to argument-driven theory (developed by Lipshitz) which proposes that decisions ought not be considered as gambles or choices, rather they should be thought of as arguments. Argument theory is unique in that it considers uncertainty as a source of motivation for the decision-maker, rather than a probabilistic expectation of outcome. Beach suggests that this is closer to actual cognitive processes than first-generation theories, but suggests the approach is narrow, (referring to a broadening of the theoretical approach by Svenson (1992) and others). Story theory and scenario theory will both be considered in more detail later.

Beach and Connolly (2005b) describe incremental theories (developed by Lindblom (1959), Lindblom (1979)) which have been derived from observation of public policy decisions. Generally these decisions have common characteristics that the only options which are considered are those where the outcome is expected to differ only incrementally from the status quo. This results in a comparative analysis between the alternatives and the status quo rather than a fundamental analysis. Choice is restricted to the attractiveness of the increments offered by each of the options, being influenced by the expected effectiveness of the solutions and the effort or resource required to implement them. Evaluation of the options available leads to greater problem understanding and redefinition of the problem. This leads to solutions which are adjusted by feedback, rather than being definitive. But, in the case of the Type 3 problems of the sustainability discourse, often the problem is not yet defined well enough so as to clear identification of available options. The challenge for the problem-structuring approach is to frame problem information so as to facilitate identification of options in relation to some form of values or objectives hierarchy.

Moral and ethical (or deontological) theories (for example, Etzioni (1988)) suggest that social science tends to ignore the influence of morals and ethics on human behaviour, possibly due to cultural differences, leading to different moral values and conventions. Etzioni argues that distinction between moral and social conventions is subtle: social norms influence behaviour by the threat of approbation or ostracism; whereas moral and ethical decisions derived from a sense of obligation, conscience, or duty from within the decision-maker. Beach and Connolly (2005b) note that to arrive at his deontological decision-making theory, Etzioni contrasts three paradigms for decision-making: the
utilitarian approach, the social approach, and the deontological approach and considers the response of each to three essential questions. These are: what is the decision-maker attempting to do? How does the decision-maker select the means to the outcome? And, who will make the decision? Considering each of these in turn, the utilitarian response to the first question is that the decision-maker is attempting to maximise self-interest. The social response is that the decision-maker is trying to behave so as to avoid punishment. The deontological response considers both the utilitarian and social issues but only in the moral context of the problem. When a utilitarian decision-maker considers the second question, the means for achieving outcome is selected using some form of cost-benefit analysis, choosing a course which is expected to provide the greatest utility. The social response is that the means selected will conform with peer group or community expectations. And the deontological response is to adopt courses of action, which according to emotional and value judgement, are morally compatible, and to reject those which are not. In answering the third question, as to who will make the decision, the utilitarian response is that individuals make their own decisions, based on their own subjective utility expectations, while the social response is that the community should dominate in determining the decision, based on expected behaviour and conformance with social rules. Whereas the deontological response is that the individuals should make the decision within the context of group and community moral principles, guided by their own moral values (Beach and Connolly (2005b)).

The value of any problem-structuring approach is that it should facilitate decision-making. Established techniques, for example, multi-criteria decision-making (MCDM), recognise that one of the main challenges is the structuring of information. MCDM has identified a number of “problematiques”, or broad categories of problem to which MCDM can be applied73. The four theoretical approaches identified here address important but different aspects of the decision-making process, and consider issues represented in the problematiques in these terms:

- Recognition theories are largely descriptive but do not explore the way in which decisions are actually made;

73 The problematiques identified by Belton and Stewart (2002) are: “choice” (simply choosing from a set of alternatives); “sorting” (arranging actions into broad categories such as “definitely acceptable” or “possibly acceptable”); “ranking” (arranging actions according to some means of reference ordering); “description”, or “learning” (formally describing the problem so actions and consequences can be better understood); “design” seeking ways to satisfy the goals identified through values-focused thinking); “portfolio” (limiting the set of actions to be considered, excluding some from a larger set).
• Story theory and scenario theory, together, demonstrate the important role of the way in which narratives are utilised to form a coherent representation of past and future situations, but do not relate this to actual decision-making behaviour;

• Incremental theories deal only with incremental variations from the status quo and thus, are ill-suited to dealing with problems systems capable of large responses to disturbances; and

• deontological theories give insight into the moral and social influences on decision-making, but these theories need to be placed in the context of the problem information.

These provide a rich source of information to draw upon in developing a problem-structuring approach to deal with Type 3 problems. In the following section, image theory, an approach which draws upon all four theoretical approaches described, above is presented here as a plausible behavioural psychological theory, which describes the actual process by which humans make decisions in uncertainty.

5.3.4 Image Theory
5.3.4.1 Why choose Image Theory?
Image theory is a “naturalistic” or second-generation behavioural theory. It is intended to be descriptive of how people are thought to actually make decisions, rather than being a normative approach. This is important because, as noted above, the problem-structuring approach to be developed in Chapter 6 is intended to align closely with real human cognitive processes. Second, as pointed out by Holton and Naquin (2005) and Coughlan (2005), image theory is well-suited to decision situations which include strong intuitive, qualitative or values-based issues, because of the way in which values are embedded in the decision-making process itself, through the representation in the value image. Because the Type 3 problem, with its multiple dimensions of belief, moral influences, and values, is of particular interest here, image theory has a distinct advantage over theories which are normatively based. The linkage between the decision-maker’s goals and objectives, the decision-maker’s actions, and the underlying value system is not merely able to be identified but is placed at the heart of the decision-making process. Furthermore, not only are values placed at the centre of the decision-making process, but image theory has been argued to be consistent with three commonly considered ethical systems: Kantianism, Utilitarianism, and Virtue Ethics (Morrell (2004)). As a practical example of
this, which is close to the sustainability discourse, is the application of image theory to consumer choice in relation to social responsibility decisions (Nelson (2004)).

Image theory proposes that the decision-maker utilises three types of image (Beach and Mitchell (1987), Beach (1990), Beach and Connolly (2005d)):

- The “value image”, which helps the decision-maker frame the problem in the context of their beliefs and values and what they believe is right. The value image consists of the decision-makers “principles”, that is the criteria which guide the determination of whether or not a decision is right or wrong. It represents the beliefs, morals, and ethics of the decision-maker, reflecting the decision-makers view of how people ought to behave in making decisions;
- The “trajectory image” is the decision-maker’s representation of the goals that have to be achieved in making the decision. The trajectory image represents where the decision-maker wants to end up. It is characterised by some image of an “ideal future”. These goals can be a set of concrete action plans or they can be abstract things which the decision-maker wishes to achieve; and
- The strategic image is the collection of plans, tactics, and forecasts which together make up the decision-makers representation of the way in which they will achieve the trajectory image. Plans are conceived in the abstract and materialise as observable behaviours in the form of tactics, or the specific actions which the decision-maker intends to deliver progress towards the goal.

There are two types of decision which are utilised by the decision-maker to determine progress towards the trajectory image. These are “adoption decisions”, which determine acceptance or rejection of goals, and “progress decisions”, which determine whether or not there is a good fit between a plan being considered and the future as described by the trajectory image. The decision-maker also applies two types of test: the “compatibility test” determines whether goals under consideration are compatible with the value image, and the “profitability test” addresses which of the available choices would be expected to result in the best outcome.

According to image theory, the decision-making process proceeds as follows (Beach (1990), Beach and Mitchell (1998), Beach and Connolly (2005d)): 
• The decision-maker describes a situation in terms of existing knowledge and experience with past events;
• If there is previous experience, the decision-maker calls upon a policy to determine the means of dealing with the problem;
• If there has been no previous experience or the previous experience was unsuccessful, the available options are screened, using the compatibility test. The best alternative is then selected according to the profitability test;
• Progress decisions are made through evaluating the plan to assess whether the goals will be achieved if the plan continues to be followed;
• By comparing the outcome, which is likely to eventuate if the plan is followed, against the trajectory image, the compatibility test can be used to determine whether or not the plan is to be maintained or replaced.

This approach appears to have an advantage over the earlier prescriptive and first-generation behavioural theories in that it provides a framework which explains diagnosis of the task, a means to identify and select action, and a mechanism by which to monitor progress towards the intended outcome (Beach (1997a)).

There is now a significant body of research which has tested various aspects of image theory, finding it to be robust (for an extensive review of this research see Beach and Connolly (2005c)). There is also a critique examining the central conceptual structure of image theory, contrasting it with traditional decision theory approaches (Connolly and Beach (1995)).

Summing up the key issues around human cognition discussed so far, it is argued that living things need to relate to the complexity of the world in which they find themselves. Humans have developed two essential thought processes, referred to here as intuitive and analytical cognition, in order to come to terms with this complexity. Together, these have made the human species extraordinarily successful. Both forms of thought are essential to success, but intuitive thought, in particular, is subject to certain biases. To ensure that we are not misled by these biases, we need to structure information about problems we encounter, so that we can determine how well our thought processes produce representations of these objects and phenomena. We do this by considering whether these representations are rational (that is, the extent to which they are coherent.
with the paradigms which represent our best understanding of the world) and whether our ideas accurately represent (or correspond to) the phenomena to which they refer.

The next challenge is to identify ways in which the tacit knowledge of personal constructs and images can be made explicit, so that representations of problem complexity and uncertainty can be communicated and considered by the domain of interests and ultimately resolved. It is proposed here that this can be addressed using two devices: first, there needs to be some visual representation of the mental image (but recognising the limitation that not all aspects of the image can be represented visually). Second, there needs to be some mechanism by which various images can be located in space and time.

The following section will develop two concepts: the “map” and the “narrative”, arguing that these are not simply devices or artefacts, which facilitate communication, but are deeply rooted in human thinking as fundamental cognitive functions. That is, both the map and the narrative are manifestations of the way in which humans actually think. The first to be considered is the map.

5.3.5 Maps – visual representation of cognitive information

Maps provide a means to combine a body of intuitive and analytical information and thought, depicting it in a single, physical, visual representation. Unlike numbers, for example, which are “hard”, precise, and atomistic (Funtowicz and Ravetz (1990)), the map is “soft”, imprecise, and holistic, representing the entire system (Robinson (1992)). Maps contain a combination of what we know and what we believe (Fiol and Huff (1992)). But by its very nature, a pictorial or graphical representation of information contains imprecision and uncertainty. For example, to make them legible, roads on topographical map are not drawn precisely to scale; cities may be represented by circles or stars. Also, the actual drafting process itself is subject to error. But in addition to this, maps reflect the map-maker’s own interpretation of information. For example, early navigational maps simply left a blank space on the map if information was unknown. Places considered to be dangerous would be decorated with fearsome creatures (Funtowicz and Ravetz (1990)). Maps can be drawn to widely differing scales, to include greater or lesser amounts of detail. They can have many dimensions or overlays (for example, contours, road systems, rail systems, utilities, population density, etc – the list is almost endless), and they can have information highlighted through drawing conventions.
and colour schemes (for example, different colours representing different vegetation or climatic conditions, socio-economic conditions and so on). There is no analytical analogy to many of these devices – for example, in mathematics, discontinuities are difficult to deal with; and there is no means to introduce emotion or feeling. Similarly, textual description cannot hope to capture the richness of information and interrelationships which are possible through the visual depiction of the map (for an extensive consideration of the depiction of quantitative information, see Tufte (1983)).

Map-making techniques evolved and developed along with progress in mathematics and geometry, with different geometrical rules being established to represent different perspectives on the information. These also introduce inaccuracies to the representation which need to be taken into account. Modern topographical map-making can be extremely detailed and precise (for example, ordinance maps and navigation charts) but by no means all maps are produced with such scientific objectivity. Maps can have many uses and may be highly abstract (for example, a map of the London Underground railway system\textsuperscript{74}). Maps can reflect differences in political perspectives (for example, where disputed territories are shown; even choice of projection may have political undertones – a Mercator projection shows territory closer to the poles as being larger than that closer to the equator). Political maps are coloured differently to geographic maps, often being intended to reinforce political propaganda\textsuperscript{75}. In the last 50 years, the subjectivity involved, in both the creation and interpretation of maps, has been realised and received considerable attention.

Until the 1940s, the increasing sophistication of cartographic science that had taken place over the previous couple of centuries had led to cartography as being thought to be a largely objective activity aiming at nothing more than “making a map” (Crampton (2001)). But in the last 60 years or so, two streams of thought suggest that map-making is not simply a cultural artifice, but rather has deeper cognitive origins. The first of these was the consideration of the cultural, social, and epistemological considerations of maps and map-making; and the second was work done in cognitive psychology.

\textsuperscript{74} Such a map is highly symbolic – it is designed for people who are familiar with the geography but need the map to locate a particular station in relation to others, all of which are familiar.

\textsuperscript{75} See, for example, maps prepared by India and Pakistan of the disputed territory of Kashmir.
In social and cultural terms, a map cannot be considered to be objective – at the very least it is a values-laden representation of the system it purports to describe. It has both conscious and unconscious distortions as a result of the process by which the map is developed. Each step of the map’s preparation – first, selection of the information to be presented by the map author to the cartographer, then, interpretation of this by the cartographer and finally, reinterpretation by the map reader, will be seen through the “lenses” of each individual and influenced by their individual values. Hence, a map cannot be considered to be a purely objective depiction of the “terrain” it represents – to do so mistakes the map for the territory (Robinson (1992)). The map is a product of the discourse between the author, the cartographer, and the reader. Indeed, there is considerable subjective separation between the map and the original thoughts of the map author (Cossette and Audet (1992)). In other words, increasingly, maps are being seen in a similar light to texts or narratives – both as a means of communication and as social constructions, which represent the values of the map author, the cartographer, and the reader. Some postmodernist commentators have even gone so far as to suggest that cartography is no longer simply a means of communication, but has become a means of representing power relationships and a means of constructing knowledge itself (Crampton (2001)). The conclusion that maps function, both as a means of communication and as an important cultural and social device, suggests that the widespread use of maps might have a more fundamental cognitive foundation, analogous to the way in which the narrative appears also to have a psychological basis, as will be argued in the last section. This cognitive aspect of the map will now be considered.

Work in cognitive psychology done in the 1940s challenged the then prevailing view of animal psychologists, that the behaviour of animals in a maze is nothing more than a simple stimulus-response mechanism. Tolman (1948), proposed that rats develop a “cognitive map” which enables them to process the stimuli that they encounter and

76 Cossette points out that the final cognitive result is a mental representations formed by the reader, reflective of the cartographer’s mental representation, which itself is formed from the discourse between the cartographer and the map author. Hence, there cannot be any direct correspondence between the mental representations formed by the reader and the original mental representations held by the map author.

77 Crampton argues that in order to fully understand the purpose of the map, it must be deconstructed, examining the reasons for the map to have been created in the first place, identifying the intended reader, understanding the changes which take place in social history over time and influence a maps accuracy, as well as the power relationships and the extent to which these influenced the preparation of the map.
suggested that it was likely that human cognition was similar\textsuperscript{78}. As noted earlier, work done in the 1970s and 1980s resulted in two quite distinct models of the cognitive representation of information (Evans (1980) – also see the discussion earlier in this chapter on the different approaches of Kosslyn and Pylyshyn). So-called “propositional models” assert that information is stored in the mind as lists, with networks linking abstract representations of meaning. Related to this approach is the concept of the “schema” – that cognitive maps are “schematic structures” which assist people in the location and orientation of environmental information (Axelrod (1973), Kaplan (1973)).

The second approach is the view that information is represented cognitively through some form of “image”, which is roughly isomorphic with the real world. As noted earlier, it is not particularly important which of these approaches is the more accurate. Rather, the point is that there appears to be some form of mental “mapping” which is a cognitive process that enables the individual to store and recall both logical and propositional information regarding the nature of the physical environment and the individual’s place in it. As Kaplan suggests, this is an important mechanism by which information is structured, in order to facilitate decisions both for short-term, moment-to-moment decision-making and long-term, contemplative deliberation.

In summary, the convergence of sociology, cultural theory and psychology suggest that maps are the physical manifestation of important cognitive, social, and cultural processes, which allow us to form simplifying representations of the highly complex environment and problems we encounter. Some of these are simple, day-to-day problems that require little thought; while others can be highly complex problems, requiring deep thought, contemplation, and reflection. Maps enable us to represent both our intuitive and analytical thoughts in a single physical, depiction. We can represent issues on many dimensions and using many metaphors and symbols – shapes, colours, patterns, and words can be combined in ways which are not possible through linguistic communication. Maps enable us to give physical representation (albeit somewhat imperfectly) to the constructs and images which we form in our minds and which we need to communicate with others in order to be successful in our environment. Maps – both physical and cognitive – enable us to place ourselves and our thoughts in the \textit{three physical dimensions of space}. But maps, by themselves, do not allow us to locate ourselves

\textsuperscript{78} In a series of experiments with laboratory rats proposed that rats learn by developing a “field map” of their environment and that a more appropriate model of the rat’s cognitive processes is a “map room” rather than a “telephone exchange”.

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adequately in the remaining dimension of time\textsuperscript{79} (Taylor (1990)). Furthermore, maps can identify and represent inconsistencies in the events and phenomena we represent but maps themselves cannot resolve them. To locate ourselves in the dimension of time and to resolve the inconsistencies in our mental models, we need the narrative.

5.3.6 Story-telling – narratives and scenarios

Narrative and story-telling is as old as humanity itself. It predates writing and occurs in virtually every human society and culture. Through most of the history of humanity story-telling has been the principal means by which knowledge has been transferred from individual to individual and from generation to generation. Much written information is contextualised in some form of narrative or story. Although there would be few who would not accept the importance of story-telling in human society and culture, only relatively recently have theories emerged which propose that narrative and story-telling are not just cultural instruments for communication but rather may be important at a more fundamental, \textit{psychological} level. It is this specific context of narrative that is of interest here.

Since the days of Freud and Jung, narratives have played a part in psychology (Freud conceived of dream narratives; Jung considered universal life myths) (McAdams (2006b)). But it was not until the 1970s, that specific narrative \textit{psychological} theories emerged. These have their origins in social philosophy, the social sciences, and anthropology and arise from a systematic, critical exploration of narrative and story-telling. They proposing that people create “life stories” which they use to define their own identity and meaning, integrating past experiences and anticipating future events in a way which provides coherence between otherwise inconsistent and discordant experiences and phenomena. These approaches are largely constructivist – people create stories to make sense of their lives. We live within and by means of stories which we create to make sense of a complex world (Mair (1988)). Influenced by this interest in narrative and story-telling, psychologists and psychoanalysts began to examine narrative as a means of understanding cognitive processes and exploring the use of narrative in therapy. Some (for example, Howard (1991)) have even suggested that all thought may be considered as instances of story-construction and narrative although Russell and Lucariello (1992) reject such a position as being too broad. But this identifies two important questions:

\textsuperscript{79} That is not to say that certain types of maps cannot be specifically constructed to represent the time dimension.
what is meant by narrative? and how might narrative be considered in psychological terms? Following McAdams (McAdams (2006a), McAdams (2006b)), the position taken here is that narrative sits at the interface between cognitive science, cultural psychology and personality psychology. Hence, first, further consideration will be given to what is meant by narrative itself. Then, two theoretical approaches taken by cognitive psychologists will be introduced, which relate narrative to psychological theory discussed earlier in the chapter.

5.3.6.1 The nature of narrative
Richardson (2000) notes that there have been four approaches to the definition of narrative, with two common ones being “temporal” and “causal”. Richardson cites Prince’s definition as “the representation of at least two fictive events in a time sequence, neither of which supposes or entails the other” and Cohn’s causal definition: “a series of statements that order causally-related sequences of events that concern human (or human-like) beings”. He offers his own definition: “narrative is a representation of a causally-related series of events”. Connell et al. (2004) suggest that narrative is a social construction which has emerged from other social constructions, such as language, values and shared meaning. They argue that although most emphasis has been on written narrative or text, narratives can also exist in words or pictures. Pentland (1999) identifies five characteristics of narrative. There is a time sequence, so that the narrative has a beginning, a middle, and an end.

Narratives are always about people or things and there is a set of characters or actors which forms part of the thread which holds the narrative together. The narrative is told from the perspective of a story-teller or narrative voice, whose point of view and values are reflected in the narrative itself. And narratives have a “canonical” or evaluative frame of reference, which provides an explicit value set or moral standard against which the actions in the narrative can be evaluated. Pentland also notes that a variety of devices are used to add richness to the events described in the narrative to aid interpretation. Furthermore, Connell et al. (2004) argue that narratives are constructed on four conceptual levels: they refer to what is actually written or said as the “text”. Beneath the text is the “story” – a recognizable perspective, reflecting the values of the story-teller, selective in its omission or inclusion of specific material. Beneath the story is the

80 The other two definitions are “minimal” and “transactional”. Richardson rejects both of these, on the grounds that they are unsatisfactory because they are too inclusive.
“fabula”, which is the general structure of the narrative, with clearly recognizable features. (For example, in organisational studies, Martin et al. (1983) found seven distinct story types which could be delivered with either positive or negative emphasis. People refer to these so that they may adjust to the “dualities” or tensions in the organisations – such as distinctions between equality and inequality, control and lack of control – which may exist between organisational and individual needs.) And at the fourth level, beneath the fabula, is the “generating mechanism”, the situation and processes which lead to construction of the fabula.

Although it is clear that there are psychological influences at work in the construction of narratives, none of this necessarily implies that narrative construction is essential to human cognition – construction of narratives and stories may be nothing more than social or cultural practices, which are common to humans in coming to terms with the complexities and inconsistencies of their environment. However, in the 1970s, a number of psychologists began to develop theoretical approaches, framed around the proposition that construction of narratives is a fundamental cognitive process (Baumeister and Newman (1994)). Typical of this work is Kintsch and van Dijk (1978), Trabasso and van den Broek (1985), Perrig and Kintsch (1985), and Hastie and Pennington (2000). The work of Hastie and Pennington is noted particularly here because of its comprehensive development of a theory of story-telling and explanation-based cognitive processes over a long-term research program.

Hastie and Pennington (2000) developed an explanation-based, decision-making theory to describe how people make decisions across a range of professional disciplines (such as law, engineering, medicine, politics, and so on) and extend this thinking to life in general. It is applicable to those decisions which are made where there is a large amount of interrelated evidence, whose implications must be evaluated in order to determine courses of action. The approach is fundamentally different to the traditional normative models such as utility theory (Edwards (1954a), Edwards (1954b)), cognitive algebra (Anderson (1979)), or social approaches, such as the lens model (Brunswick (1949), Hammond (1955)), and social judgement theory (Brehmer (1984), Brehmer (1980)). The approach could be considered to be a second-generation behavioural theory, in that it seeks to propose a model of how people actually evaluate evidence in decision-making. Hastie and Pennington note that the details of the evaluative model will be specific to the
domain in which the decision takes place\(^8\) – the theory was developed over 20 years or more through investigation of the way in which jurors make decisions in criminal trials (Pennington and Hastie (1981), Pennington and Hastie (1986), Pennington and Hastie (1988), Pennington and Hastie (1991), Pennington and Hastie (1993)). They found that jurors develop narrative structures to arrange and assist with the interpretation of evidence. The “explanation” is a mental model (c.f. Johnson-Laird (1980)), which attempts to identify causal relationships between events and phenomena, in order to provide a coherent, plausible framework to explain the set of events under consideration.

The central process in the explanation-based model is the story or narrative construction, which consists of three underlying processes: the construction of the story to evaluate information (in the case of a legal trial, the evaluation is of the evidence presented); forming a mental representation of a number of alternative decisions; and reaching a decision by classifying the narrative in a way which fits the decision criteria most appropriately (in the case of the legal trial, determining the verdict category which most closely matches the narrative classification). An important feature of Hastie and Pennington’s model is their proposition that it is the narrative itself which establishes the decision – formulation of the narrative, its use to develop a mental representation of the situation, and the ultimate classification process against decision criteria is a single, continuous, cognitive process which determines the decision.

However, Hastie and Pennington’s work (and also the other similar approaches cited above) consider decisions being made now in relation to past situations or events, whereas the types of problems encountered in sustainability and sustainable development typically involve decisions to be made now regarding anticipated or future events. There does not appear to be the same degree of substantiated theoretical treatment of the cognitive processes used to determine solutions to anticipated or future events. Several theoretical models have been proposed (for example, Chermack (2004), Chermack (2005)) but these have not been confirmed by experimental research. One such approach, referred to by Beach in contextualising image theory, is that of Jungermann and Thüring (Jungermann (1985), Jungermann and Thüring (1988)). They have given consideration to the cognitive processes involved in future events, which they refer to as

\(^8\) For example, a physician undertaking a diagnosis will have a different set of causal rules and structures to those adopted by an engineer during process design, or a diplomat’s explanation of the relationships between military and political forces in a strategic theatre.
scenarios. Developing the notion of a mental model (which is consistent with Hastie and Pennington’s approach), Jungermann and Thüring propose a theoretical framework consisting of four steps. First, knowledge of the problem is activated in the memory by drawing upon the “world knowledge” in the individual’s long-term memory, suggesting that this representation can be thought of as a “causal net”. This is followed by development of an internal representation of the problem domain, which maps the important features of the problem. The mental model is then run and produces inferences regarding possible scenario outcomes. Knowledge regarding the scenario is then constructed by selecting the appropriate inferences, according to the intention of the decision-maker.

The important point to draw from this brief consideration of narrative is that human preoccupation with story-telling in narrative does not appear to be simply a social tradition. Its ubiquity alone suggests that narrative and story-telling is a fundamental cultural and psychological human phenomenon. Pennington and Hastie’s work provides a plausible, substantiated cognitive framework in relation to interpretation of past events and Jungermann and Thüring’s work, by no means inconsistent with that of Pennington and Hastie, provides a conceptual framework for consideration of future events. Both approaches are consistent with personal construct theory and image theory, which form cornerstones of the problem-structuring approach developed in the next chapter.

The widespread occurrence of narrative approaches, and their apparent importance at cultural, social, and psychological levels, suggests that the development of a narrative approach to problem-structuring could provide a broadly attractive means of engaging a diverse domain of interests. And in conjunction with the map, the narrative allows physical representation of cognitive processes in all four dimensions, thereby providing the means by which inconsistencies and gaps in our knowledge may be represented, explored, and better understood.

In broad terms, the problem-structuring approach to be developed in the next chapter provides a means by which problem information can be represented spatially, using innovative cognitive mapping devices, with narratives providing the way to give temporal context, to identify gaps in problem information, and to assist in the representation of issues such as values, beliefs systems, and morals. The intention is to use this approach
to condition problem information, so that it can be readily integrated into the data structure utilised in formalised decision analysis techniques, such as multi-criteria decision analysis.

5.4 *Summary*

This chapter sets out to gain insight into the way in which human cognitive processes function in attempting to deal with problem situations, which are complex and uncertain. In order to reduce problem complexity and to deal with uncertainty, humans have evolved two modes of thought: intuitive and analytical. This bimodal system of cognition has made the human species extraordinarily successful. As problem complexity increases, in order to determine whether or not a judgement or decision is likely to be successful, consideration needs to be given to two questions: first, whether or not the judgement is rational within the prevailing paradigm; and second, whether or not the judgement is (or is likely to be) accurate. As problem complexity increases – as happens with Type 3 problems – issues of beliefs, values, power and so on influence assessments both of rationality and accuracy. To understand this in greater depth, various aspects of cognitive psychology have been explored with the ultimate goal of developing a problem-structuring approach, so that consideration of the problem can be broadened. This broadening is done for two reasons: to allow the inclusion of as wide a representation of the domain of interests as possible, thereby increasing the richness of problem information; and to prepare the problem for more established analytical approaches.

The key issues identified are these. Humans form mental representations (or constructs) in order to locate themselves within their physical environment and to reduce complexity, so that they can deal with the situation within their cognitive limitations. According to Kelly (1955a), these constructs are triadic in nature, whereby two dichotomous representations are contrasted against a third. Beach and Mitchell (1998), Beach (1998), Beach and Connolly (2005a) proposes that humans utilise three types of image, together with various types of decisions and tests in order to make judgements and reach decisions in uncertainty.

Humans create maps (in particular cognitive maps) in order to organise events and phenomena within the three spatial dimensions. As well, narrative (both verbal and
textual) is used to contextualise events and phenomena spatially but with particular emphasis on locating these events and phenomena in relation to the dimension of time and to reconcile inconsistencies and gaps in our knowledge.

In order to usefully consider these in the problem-structuring approach to be developed in Chapter 6, these might be summed up as follows:

C1. Humans form mental representations of things and phenomena which they encounter in World One. These appear to consist of some form of dynamic system of depictions, non-visual patterns, and linguistic representations which can be stored, recalled, processed, correlated, and evaluated (Gregory (1953), Broadbent (1958), Boulding (1956) and Miller and Galanter (1960), Kosslyn and Pomerantz (1977), Kosslyn (1980b), Kosslyn (1980b), Kosslyn (2005), Pylyshyn (1973), Pylyshyn (2002), Pylyshyn (2003)). These representations, or “images”, form the substance of our World Two knowings and are used to construct World Three propositional knowledge;

C2. The human mind can only retain about five or six units of concentration in short-term memory at any one time, but has a very great capacity to retain information in long-term memory and to recall it to short-term memory as required (Miller (1956), Simon (1969));

C3. Fundamental to the way in which humans construct their conceptions of reality is the “dichotomous construct”, in which three representations are needed: two of these represent opposing poles of a similarity, against which the third representation is contrasted. People then make use of a “scalar” to represent the magnitude of the contrast (Kelly (1955c), Bannister (1962), Bannister and Fransella (1971), Kenny (1984), Fransella and Neimeyer (2005));

C4. When confronted with situations where there is considerable uncertainty, humans form judgments, make choices, and reach decisions using processes, which can be adequately described using the “image theory” model (Beach and Mitchell (1987), Beach (1990), Mitchell and Beach (1990), Beach (1997b), Beach and Mitchell (1998), Connolly and Beach (1995), Beach and Connolly (2005d)). Of particular importance here are the three types of image utilised by the decision-maker. The “value image” helps the decision-maker frame the problem in the context of their beliefs and values and what they believe is right. The “trajectory image” sets an agenda or set of goals. And the “strategic image” is an image of
plans to guide behaviour and to create impressions of what the future will be like (Beach and Mitchell (1987), Beach (1990)). Image theory is well suited to problem situations which have strong intuitive, axiological, or values-based, issues, because of the way in which values are embedded in the decision-making process itself, through the representations contained in the value image (Holton and Naquin (2005), Coughlan (2005));

C5. Humans attempt to relate spatially to things and phenomena in the real world, using various forms of cognitive map. The schematic structures of cognitive maps provide a means to combine both intuitive and analytical information and thought, depicting these as a single representation. Such maps become holistic representations of the entire system under consideration. They need not be specifically isomorphic, but represent an important mechanism by which information is contextualised and structured. This is to facilitate the reaching of decisions both, for short-term, instantaneous decision-making and long-term, contemplative deliberation (Tolman (1948), Axelrod (1973), Kaplan (1973), Evans (1980), Funtowicz and Ravetz (1990), Fiol and Huff (1992));

C6. Whilst cognitive maps provide the means for humans to spatially orientate problem information, there appears to be an additional cognitive process to contextualise problem information in the temporal dimension. The use of narrative is an important cognitive and social device to integrate temporal and spatial representations of problem information. The use of narrative is also thought to be an important cognitive device for reconciling apparent inconsistencies in knowledge of the problem situation (Kintsch and van Dijk (1978), Bennett (1978), Trabasso and van den Broek (1985), Perrig and Kintsch (1985), Mair (1988), Baumeister and Newman (1994)), and Hastie and Pennington (2000), McAdams (2006a), McAdams (2006b)).

C7. Taken together, the cognitive map and the narrative allow physical representation of cognitive processes in all four real-world dimensions and provide a means to reconcile inconsistencies and identify gaps in our knowledge. Thus, we come to understand better the various aspects of problem complexity.

The thrust of the remainder of this dissertation is to build a problem-structuring approach, based upon the theoretical concepts of Kelly’s personal construct theory, Beach’s image theory and to develop rigorously conceived cognitive mapping devices and
narrative approaches. These are to be consistent with the philosophical principles argued in Chapter 4 and the psychological theory discussed in this chapter.

5.5 References

Aristotle (350BCE) *Nicomachaean Ethics*.


Chapter 5 – Cognition, Judgement, and Decision-Making in Uncertainty…


Pascal, B. (1660) *Penseés*.


