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The Development of Professional Judgement Capacity through Activity Led Learning

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The Development of Professional Judgement Capacity through Activity Led Learning

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Abstract

The unique contribution to knowledge of this research is the study of the development of judgement capacity in apprentice and undergraduate engineering learners in Activity Led Learning (ALL) environments. Four case studies of engineering students investigated the learners' experiences of making judgements in various engineering undergraduate and apprenticeship programmes. A phenomenological research methodology was used to infer the learner's judgements from the learners' dialogues and actions that were observed during the learning activity.

The findings of the study indicate that the experience and incidence of the learners' exertion of judgement is dependent upon the construct of the ALL environment to provide a problem space with potential for disjuncture, and the intentionality of the learners. The learners did not solve problems by a linear progression but repeatedly re-activated experiences and knowledge, exercising judgements until the states of disjuncture were satisfied leading to the conclusion of the problem. Heuristic judgements that may result in decision making errors tended to dominate the problem spaces though their incidence did not appear to be influenced by the technical or socio-technical demands of the project problem spaces.

This thesis concludes that in ALL environments, projects of sufficient length and complexity similar to realistic professional practice, may enable students to acquire the practice of better judgement through disjuncture and by re-activating learning experiences and importing analogies into new problem spaces. However, to acquire skills and knowledge to improve judgement capacity, requires specific and purposeful interventions within ALL that enable the learner to know when heuristic judgements are reliable or otherwise unreliable, and acquiring reasoning strategies to compensate for the effects. It is proposed that in such interventions the learner learns to record their own judgements as they are exerted and to reflect critically on those judgements and their consequences. It also requires that any ALL project that aims to promote judgement capacity has in place assessment instruments that specifically consider the learner effort in the self development of judgement.

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Conference Papers

Appendix 1

Igarashi, H., Davies, J.W., & Wilson-Medhurst, S. (2014). Activity Led Learning and Developing Professional Judgement Capacity in Undergraduate Learners. SEFI 42nd annual conference proceedings ISBN: 978-2-87352-010-6

Appendix 2

Igarashi, H., Tsang, N., Davies, J.W., & Wilson-Medhurst, S. (2015). Activity Led Learning Environments in Undergraduate and Apprenticeship Programmes. PAEE annual conference proceedings IJCLEE joint conferences.

Appendix 3

Igarashi, H., Tsang, N., Davies, J.W., & Wilson-Medhurst, S. (2015). Designing Activity Led Learning to Promote the Development of Professional Judgement Capacity. IRSPBL annual conference proceedings IJCLEE joint conferences.

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1. Introduction

1.1 Background

This thesis began as a project proposal from the Faculty of Engineering and Computing at Coventry University to study the potential of Activity Led Learning (ALL: discussed below) to enable the development of students from new university entrant to new professional entrant and to develop an appropriate theoretical framework for learning which supports that process and the development of judgement capacity. Judgements are essential cognitive functions of rationality. The making of decisions based on sound judgements is expected of all professionals, and to understand the pedagogic contexts in which judgement capacity is exercised and developed is to illuminate how one of the most important aspects of professional conduct is acquired.

Four case studies were written on the activities of learners engaged in Activity Led Learning (ALL) interventions in various engineering environments. The purpose of the case studies was to conduct a phenomenological enquiry into the learners' experience of making judgements in engineering projects and to understand the kinds of judgements that they made during the ALL projects.

Undergraduate students from the departments of Civil Engineering, Architecture and Building; Aerospace; Mechanical, Automotive and Manufacturing within the Faculty of Engineering & Computing at Coventry University and apprentices from a subsidiary of British Engines participated in the studies. The project scope was originally intended to study ALL within Coventry University, however due to my working relationship with British Engines the opportunity arose to extend the study beyond undergraduate degree programmes to include engineering apprentices. It was envisaged that the increased breadth to the study would strengthen any conclusions or reveal any incidental factors from the diverse environments.

Founded in 1922 in Newcastle upon Tyne, the British Engines Group manufactures and supplies equipment for the oil and gas industries such as high integrity subsea valves, hydraulic motors and pumps and electrical glands and fittings. The manufacturing activity is principally the machining of corrosion resistant alloys by CNC machining, fitting and assembly. Coventry University is located in the city of Coventry, England. It became a public research university in 1992, and was formerly known as Lanchester Polytechnic until 1987 and Coventry Polytechnic before attaining university status. The university had 19127 enrolled students between 01/08/2013 and 31/07/2014. The Faculty of Engineering and Computing has 5 departments; Aerospace, Electrical and Electronic Engineering; Civil Engineering, Architecture and Building; Mechanical, Automotive and Manufacturing Engineering; Computing; Mathematics and Physics.

ALL has been broadly adopted across the faculty of engineering and computing as a model of problem and project based learning. ALL can include different types of learning activity where activity is put before passive knowledge transfer so that the learner has an environment in which they have to think in order to construct analogies and networks of knowledge. For the purposes of this research, however ALL has been interpreted as a project based learning paradigm.

This places learners in challenging situations in which they have to exercise judgements. The overall aim of this research project was to determine the types of judgements that are exercised by the learners and in what circumstances so that the way ALL affects the exercise of judgement might be better understood. This study extends previous research on student engagement, retention and satisfaction in ALL at Coventry University. The principles of ALL are considered further within section 2.4.1.

Two distinct approaches were combined in a single paradigm in order to determine the kinds of judgement that learners make in complex ALL environments. These were the taxonomy of judgements proposed by Lipman (2003) and the System one and System two models of thinking hypothesised by Daniel Khaneman (2011). It was conjectured that the nature of judgement would be different depending upon the environment in which it was exercised. Consequently a way of assessing the 'rationality' of an engineering problem space by plotting its technical demand and socio-technical demand was adapted from an idea by Gattie et al (2011).

My unique contribution to knowledge is the study of the faculty of judgement in learners and the determination of factors that promote the exertion of judgement and development of judgement capacity in the complex environments of Activity Led Learning.

1.2 The Research Questions

Three research questions were formulated to guide the project.

1. Where does Activity Led Learning (ALL) as defined by Coventry University, fit within existing models of learning and the development of professional judgement capacity in learners?

2. How does current ALL practice fit in this framework?

3. What is the learners' experience of making judgements in the ALL environment and what does that tell us about the construction of ALL to promote the development of capacity for professional judgement?

2. Literature Review

This literature review examined the body of knowledge considered relevant to the faculty of judgement and its learning. It guided the choice of a research methodology and methods and provided the background knowledge that informed the first 2 research questions. Reading was taken from contemporary researchers and the seminal works of past experts in the fields of philosophy, human cognition, education, engineering practice and professional competence. The role of engineering education and the development of professional engineering skill is considered with the development of professional behaviours. The research methodology and qualitative method is phenomenological and predicated upon the works of Kant, Husserl and Merleau-Ponty. Understanding of human cognitions and decision making has made major advances over the last 40 years and the latest literature in this area was used to inform this study. Different paradigms in Activity Led Learning are considered from research papers on current higher education theory and praxis.

2.1 Professional Development

2.1.1 Rationale for the Research of Judgement in ALL

This thesis focuses on judgement, the learner's experience of making judgements in engineering projects and the development of judgement capacity in ALL environments. The selection of this particular field of research was based upon the following rationale. This PhD project was one of a number of ongoing research projects into the development of ALL at Coventry University. The project was funded by the faculty of Engineering and Computing specifically to research the current practice in ALL across the faculty and to determine whether or not, the ALL environments and interventions contributed to the development of professional behaviours. The scope of the research area was defined initially due to this prior body of work and pre-existing propositions to consider the development of judgement in the context of the learner experience. The focus on judgement became more apparent in the literature review that was guided by the University's definition of ALL which is reproduced on page 19. The definition expresses the view that the learning environments of ALL and real professional practice are analogous. Based on this assertion the literature review examines ALL practice and other educational frameworks, and perspectives on the nature of professional practice, competence and behaviours.

Here I briefly outline the position of this thesis with regard to engineering education and expert performance. Cowan (2010), Eraut (1994) and Hager (1999) all discuss professional practice, the complex nature of the environments in which practice takes place and the necessity of professionals to have the capacity to make sound judgements. The case is made that whilst sound judgement capacity is an objective of professional development, it takes cognitive effort to acquire. Gattie et al (2012) draw our attention to the pressures to reform engineering education to be more inclusive of the holistic socio-technical issues facing professional engineers. The difficulties and the uncertainty inherent in professional engineering practice discussed by Trevelyan (2010) and Mills & Treagust (2003) further imply the need for sound judgement and illustrate the scale of the challenge in professional development.

Some educational theorists however do not specifically mention judgement. For example it is not explicit in Kolb's experiential learning theory nor is it mentioned in communities of practice (Lave 1991), (Wenger 2012). In the work of these authorities however, the role of judgement is implicit. Judgements are the cognitive mechanisms by which we make sense of the world. In the formation of new purposes and understanding, the exertion of judgement is a fundamental procedure in making sense of propositions and learning. Lipman (2003:25,96 & 97) however in discussing critical thinking in the context of educational communities of inquiry specifically does refer to judgement and provides a comprehensive taxonomy (ibid 2003:281- 288). The literature indicates that judgement is not explicitly considered in many accepted models of learning but appears to be an important feature in explaining the nature of professional performance. From this it was determined that focussing the research on the exertion of judgement in ALL environments would provide an opportunity to make a unique and fundamental contribution to understanding the way learners experience the exertion of judgement and reasoning. It may also be possible to deduce whether or not ALL promoted professional behaviours and the faculty of professional judgement in particular.

2.1.2 The Changing Landscape in Engineering Education

One of the objectives of undergraduate engineering education programmes is to provide graduate engineers with the knowledge and skills to begin employment as professional practitioners and the university therefore is key in enabling the development of the individual from new university entrant to new profession entrant. In more general terms Kolb (1984:85) draws our attention to the function that education should have in shaping the attitudes of students toward learning by engendering a thirst for knowledge and positive attitudes toward learning.

Because abstract propositional knowledge is one of the most salient though not necessarily one of the most important features of engineering practice, there is a common belief that engineers work principally in a technical domain characterised by problem solving and design (Trevelyan 2010:384). In consequence there is an expectation that the learning and instruction of engineering should focus on domain specific knowledge in preference if not exclusion to other important issues. In 'Experiential Learning' Kolb (1984:184) for example, refers to the requirement of the science based professions and especially engineering to have facility in abstract conceptualisation in the use of advanced technology to solve real world problems. While he goes on to explain that different managerial skills are needed for engineers moving into management roles he does not mention the broader social and holistic issues which have always been a feature of engineering practice even though they have been largely overlooked. Other authors have noted the developing dialectic between educating for a system that has produced the advances of the last 100 or more years and the view that engineering is a social construct and its educational systems should be modified to give full weight to learning and thinking that embraces the holistic social environment in which engineering transactions are made (Lipman 2003; Mills and Treagust 2003; Gattie et al 2011). Traditionally, educational programmes have approached the development of the learner on the axiom of domain specific or propositional knowledge and testing that knowledge serves as the standard for entry into the various levels of the profession.

2.1.3 Knowledge and Expert Performance

While there are standards of professional conduct expected by the professions they are often quite broadly defined desirable traits. There is little understanding of how professional characteristics in observation, thought and reflection can be purposefully developed and are assumed to be implicit in the learning environments of universities or work places. Dewey (1916:5) referred to these characteristics as habits of thought action and considered them essential to understanding the circumstances in which the habit functions. A professional in simple terms may be deemed competent if they have satisfied standards for propositional knowledge and can also display certain professional traits. There is however an ongoing debate as to whether some of these professional traits can actually be measured and assessed (Gattie et al 2012).

Propositional knowledge in terms of its technologically deterministic effects can be considered as two broad categories. There is the knowledge derived from the major technological developments throughout the 18th, 19th and 20th centuries which contributed to the post industrial revolution social construct and which do not change substantively. There is also other sub-domain specific knowledge which changes rapidly as new variations in established technologies emerge. With the emergence of any new major socially constructive technology becoming less likely and the transitional nature of new technological variations, propositional knowledge on its own is becoming a less valuable commodity in professional development. With the limited shelf life of new knowledge it is all the more important that effective judgement is made in its application (Cowan 2010:323). Eraut (1994:17) also discusses in detail the validity of professional knowledge and the making of competent decisions. He contrasts the capacity of the experienced professional to organise knowledge and make sound judgements in conditions where information is limited or uncertain with the popular view that judgement is derived from accurate scientific principles which are absolutely reliable.

In comparing new profession entrants with experts of some years experience Eraut (1994:129) further claims that the recently qualified have as great a domain specific knowledge as long standing experts. Given the nature of propositional knowledge and if we accept Eraut's position on this matter, it leads us to hypothesise that if we are unable to distinguish expert performance on propositional knowledge alone then professional expert performance can be seen to be broadly characterised by the way the professional organises and uses knowledge. Hager (1999:1) hypothesised that making better judgements represents an objective of workplace learning and that the capacity to make appropriate judgements is a defining characteristic of the cognitive growth of the individual. Many of the current challenges confronting professional engineers include human issues which impact on the solutions to engineering problems and the social constructs that may emerge as a consequence of them. The practice of professional engineers has become increasingly complex and is no longer considered to be reducible in terms of technical excellence. The professional engineer has to be able to organise and use knowledge to make sound judgements with regard to engineering solutions and their implementation and also understand holistically the consequences of the implementation of technological solutions.

Engineering education is now undergoing a slow process of change driven by strategic demands to educate engineers to become more aware of the holistic socio-technical, economic and sustainability issues relevant to modern professional practice(Gattie et al 2011:521). There remain demands that with this laudable objective any changes should not sacrifice the intellectual rigour inherent in testable propositional knowledge (ibid 2011). This presents some problems in that undergraduate programmes are of determinate length and learning how to make appropriate judgements in the use of concepts and knowledge is usually more difficult than comprehending them. Using propositional knowledge in applications and practical situations requires considerable cognitive effort and as much time needs to be devoted to the use of propositional knowledge as acquiring it. (Eraut 1994:120).

2.1.4 The Basis of Professional Competence

What constitutes or characterises professional competence? There have been a number of attempts to arrive at lists of professional competences and Eraut (1994:1) makes the case that these have all failed. The failure is not merely due to difficulties in definition and articulation though these are most common. Difficulty also arises in achieving adequate representation among the interested parties and meeting their expectations. Statements of practical and managerial competence are drawn up in consultation with selected employers. These are comprehensive lists of actions considered necessary to perform a particular job role competently and there is considerable semantic, syntactic and stylistic variation which defy inter-occupational standardisation and often contribute to over specialisation and fragmentation. In some cases, standards also include lists of desirable behaviours but here I am making the distinction that the notion of competence is a standard, defined in occupational competence and used in occupational assessment. Statements of professional competence however are unable to convey the subtle differences in context and judgement which separate actual performance from prescribed competence. According to Baartman (2008) this view is supported by Messick (1984) who summarised competence as what one knows or does under ideal circumstances whereas performance is what is actually done under existing circumstances. Chomsky (2006) drew similar conclusions in his theory of linguistics. He observed that while people have the ability to organise and develop new terms and phrases which indicate competence in the grammatical organisation of language they are often inhibited to refrain from some language forms by the requirements of social convention and custom in certain circumstances.

2.1.5 Acquisition of Professional Behaviours

It is often observed that new profession entrants are rarely seen by employers as competent and various and sometimes lengthy periods of adjustment and further development are considered necessary before they are thought to be competent or much later, expert. Frame (2013:136) cites Jaques (1986) who defined capability in terms of the capacity to carryout voluminous tasks that are complex, difficult and significant to an employer. Traditionally the transition from new entrant to competent employee is often implemented by providing the new entrant with a mentor or supervisor from whom they 'learn the ropes' or perhaps more succinctly inherit a legacy of professional practice (Eraut 1994). Potentially this has consequences for the development of professional competence. Experts considered renowned in their field have typically developed their skills over many years when they have been subject to the occurrence of the unusual and in diverse situations. Communities of practice often take many years to present enough learning disjunctures to make someone truly expert. In normal circumstances, professional practice is undemanding, the exertion of judgement is limited and no new expertise is generated. Jarvis (2006:7,54) broadly defines disjuncture as an interruption in thinking that creates a desire to satisfy a state of cognitive dissonance.

In a community of practice the new entrant is immersed in an environment where compliance to received wisdom or custom and practice is expected (Handley et al 2006:44). Professional competence is also often seen as handling cases quickly and efficiently a position which may be achieved by reducing the number of ways of thinking about them to manageable proportions rather than attempting innovative solutions (Eraut 1994:43). Such environments are not conducive to critical thinking and innovative thinkers are likely to be kept on the periphery of action. The new professional learns rules rather than how to exercise judgement through true understanding and methods of working and solving problems that may be potentially more effective never get into practice. Eraut (1994:124) supports this view in discussing the acquisition of professional competence and refers to Merleau-Ponty's claim that perception and understanding is about picking up flexible styles of behaviour rather than rules. The development of critical thinking and judgement in future engineers seems too important a task to leave to the vicissitudes of this traditional model of observational-reflective learning. It suggests a suitable environment and learning opportunities need to be provided to enhance the learning process.

2.1.6 Comparative Judgement Capacities in Professional Practice

A professional engineer is throughout employment, faced with diverse problems for which appropriate solutions have to be sought. Some problems may be readily soluble simply by resorting to the application of propositional knowledge while some others may be more technically complex but have solutions which are still reducible to applications of scientific and mathematical knowledge. There may also be the very complex and ill defined problem spaces encountered in larger projects. These may be seen to consist of smaller problems which are hierarchically and temporally dependent and also have complex socio-economic, environmental and ethical considerations. In order to solve the problem the professional engineer has firstly to define an appropriate problem space and the capacity to make the judgements that construct a rationally bounded and efficient problem space has to be learnt. The way in which a professional may be expected to make sound judgement depends upon the flow of information at that time and this may be demonstrated by looking at different professions.

Mills &Treagust, (2003:7) for example make the distinction between problem solving in engineering and medical practice. They posit that medical diagnosis is a hypothetico-deductive process relying on an encyclopaedic propositional knowledge. The clinician rapidly forms a hypothesis which is subsequently confirmed or modified when additional information becomes available. Because the hypothesis fits known pathological schemata the original diagnosis is that which is most salient rather than that which is the most probable. A clinician faced with a patient with inexplicable symptoms doesn’t have the judgement capacity to move beyond that which can be defined within a known set of pathologies. Indeed there are compelling professional ethical reasons why they should not and have to declare that the condition is idiopathic. There are situations however where a practitioner may have to make judgements in uncertain circumstances such as when to allow a patient to be discharged or how to treat a patient that displays symptoms but doesn't have archetypal test results.

In engineering however, substantive problems are both technically demanding and ill defined in terms of social and human issues and often have competing demands from different stakeholders. There may also be more than one potentially appropriate answer the veracity of which may only become apparent some time after the solution has been implemented. The way judgement is exercised will also depend on circumstantial factors. Not all judgement can be made when there is time to consider all the factors, and engineers have to be able to make judgements when information is vague, incomplete or when there is no certainty of a predictable outcome. Time is a limiting factor and Eraut (1994:66) draws our attention to the resort to intuitive decision making which occurs when decisions have to be made rapidly and with limited information.

2.2 Problem Space

2.2.1 Heuristic Judgement and Problem Space Definition

Judgement has to be exercised in different stages of a project. In the initial stages of problem space definition the scope of the problem is determined by deciding which knowledge and procedures are appropriate to arrive at a solution. Professionals do this quite rapidly because they have analogies to draw upon. Khaneman (2011:237) in considering the circumstances in which heuristic decision making may be thought of as reliable, refers to Klein's 'recognition primed decision' theory of decision making. Heuristic cognitions arise in processes in which there is simply insufficient time to consider various options. In other cases uncertainty, lack of information and time create pressure to resort to intuitive reasoning. In both situations the individual uses heuristic strategies to generate a reduced problem space that consists of potentially relevant domain specific knowledge and control strategies to enable them to negotiate the problem space. When there is time for reflection in action, the problem space can be modified iteratively. Efficiency in problem solving necessarily involves access to expert domain specific knowledge, skill in generating the problem space and using heuristic strategies to make judgements to negotiate the problem space and solve the problem. Seminal work by Newell and Simon (1971) while developing a structure for problem solving in artificial intelligence led to the Problem Space Theory of problem solving. This theory outlines the mechanism of problem space definition. One of the outcomes of the theory is that while the expert has recourse to domain specific knowledge and practised skill in making the judgements that negotiate the problem space, they have to resort to making judgements or apply heuristic strategies to redefine the problem space for each new problem they encounter. They considered this very initial stage of generating or defining an initial problem space not to be amenable to improvement through practice, however the number of likely problem spaces is reduced by experience. The sheer size and complexity of some engineering projects necessitates problem solving by teams and the way decisions are made by groups is not well understood. Schmidt et al (2007:94) cite Ohtsubo (2005) claiming that complex PBL tasks produce an environment where it is more efficient for learners to collaborate and interact in a way that also reduces cognitive load on the individual. I would say this is even more likely to be a feature of larger PjBL opportunities than PBL. In considering any potential similarities between professional and learner, Trevelyan (2010:388) points out that a comparison can be drawn between professional practice and the classroom and when the interactions between engineers in the workplace are compared with the interactions of students in a cooperative learning environment, they are remarkably similar.

2.2.2 Cognitive Mechanisms in Judgement and Team Collaboration

There are two aspects of human cognition which are great movers of human action and have evolved specifically in the context of collaboration. Therefore we might conclude they will have a direct impact on judgements made by individuals in a group and the resulting decisions made by the group. The first of these is imitation. It has been noticed by psychologists and anthropologists that humans resort to imitation of each other to a remarkable degree. Imitation is a driving factor in group cohesion, whereby members of a group identify with each other. Much of imitative behaviour is evident in cultural traditions mannerisms and dress codes and also in regional dialects and accents. It has also been considered to account for the acceptance or rejection of certain memes (Dawkins 1976).

Individuals in a group situation may make judgements based on the representativeness of an idea and its relationship to the person proposing it rather than a rational analysis of the veracity of the idea or any judgements associated with it (Khaneman 2011:91).The other aspect is one of intention attribution. This cognitive mechanism is when an observer attributes a particular intention to another. A particular example has even been observed in very young children, who can accurately tell whether someone is unwilling to give them a toy or is incapable of giving them a toy (Woodward et al 2009:191). By being able to discriminate between intention and incapability the child knows which of the persons is likely to be the best collaborator and engages more with that person and ignores the person who is deliberately withholding the toy. Adults maintain this faculty and are also able to tell in quite subtle ways the value of an individual as a potential collaborator. Where individuals exercise judgements about collaboration in a team they are almost certain to engage in meaningful exchanges of information with someone they see as a collaborator and someone who is authoritative and trusted and possibly even be antithetical to someone who they perceive as uncooperative or weak. The mediating judgements directed at collaboration however are not conclusively predictive of the behaviour of others. The tendency to want to trust and collaborate means an observer cannot always tell accurately whether or not another individual intends to perpetrate some complicated fraud in the near future.

2.2.3 Environment, Team Dynamic and Collaboration

The behaviour of individuals and the way their groups are organised affect the presentation and organisation of knowledge, the judgements that are made and the decisions which are made and implemented. Competing demands in multi-stakeholder groups make the problem space more complex rendering it more difficult to negotiate to an appropriate solution. A solution may be reached more quickly by a group with similar world views but a value judgement has to be made as to whether the solution produced is actually better than a solution derived by a group were world views compete. In most practical professional situations a professional is likely to encounter groups with diverse political and social attitudes and the aspiring professional must learn to cope with the emotive and social issues that arise in such environments (Parkin 1996:135-139).

Team work and team management are forms of expertise that many professionals do not fully possess and their obstructive or negatively impacting behaviours make them inefficient or even incompetent in group work environments (Eraut 1994:153). Despite the potential increase in costs and time, good team work where all team members are empowered, provides opportunities for sharing expertise and cognitive load and enhanced creativity due to peer stimuli and challenges. The challenge is in mitigating the effects of group think and the associated *Primus inter Pares* effect. Group think arises from our deep social identification mechanisms to belong to a group, imitation, representativeness and avoiding conflict. The *Primus inter Pares* effect is the illusion that someone who looks and sounds authoritative is authoritative, knowledgeable and making good decisions. These phenomena have pernicious effects on team coherence and team work. Unanimous decisions that are thought to be robust and the result of good judgements actually result from the representativeness bias of *Primus inter Pares* and social interaction strategies to avoid conflict. (Rosenthal, U., & ‘t Hart, P.1991:361). Decisions are thought to be the decisions of teams but in fact are the decisions of the *Primus* sanctioned by social interactions. Rose (2011) cites Irving Janis' work (Janis 1982) on Group Think theory that has discrete parts including group cohesion, structural faults and situational factors. Janis' Group Think theory is complex but in summary he identified three antecedent conditions which are group cohesion, faults in organisation structure and external factors. The occurrence of Group Think is determined by observation of the following groups of symptoms.

1. Overestimation of the group, including illusion of invulnerability and belief in group‘s inherent morality.

2. Closed mindedness, including collective rationalization and stereotypes of out-groups.

3. Pressure toward uniformity including self censorship and illusion unanimity.

Janis (1982) also gives 7 conditions that indicate defective decision-making;

a) incomplete survey of potential alternatives
b) incomplete survey of objectives
c) failure to fully examine consequences of risks
d) failure to reappraise previously rejected alternatives and threats
e) poor research and knowledge of reference class
f) selective bias in processing information
g) failure to have a worked contingency plan.

2.2.4 Distributed Expertise

In a group where there are conflicting points of view there must necessarily be discussion in order to seek resolution and disciplined discussion of the salient points that arise across the work group is an excellent way of acquiring deeper understanding of a problem space. Cam (2006:10,13) discusses Lipman and Dewey and the way that discussion enables the development of traits such as open mindedness, intellectual rigour, inquiry, rationalism and judgement that characterise professional behaviour More than technical expertise, engineering is the art of producing predictable outcomes with the unpredictability of human performances and transactions. Engineering therefore requires the development of communicative and organisational skills.

Trevelyan (2010:387) posited that the aim of engineering is to ensure products can be delivered predictably and so engineers of necessity must understand how the complex and unpredictable nature of human performance can deliver outcomes in a way which can be predicted. A large amount of the information in engineering practice is based on interaction with other people. In a typical engineering project, expertise is distributed but it may often be tacit in nature and difficult to transmit across a network of collaborators. Engineers must be capable of developing collaborative styles of working (Trevelyan 2010:386). Professional judgements have to be made in the most challenging and uncertain of circumstances and yet controversially the discussion and dialectic that occurs in such environments may prove to be fertile ground for the acquisition and improvement of judgement capacity. Lipman (2003:100) considered that discussion is the best method for improving thinking skills. When learners engage in discussion about some controversial issue with important theoretical implications they make the best use of their subject knowledge, employ good reasoning and display their capacity to make the most reasonable judgements.

2.2.5 Professional Judgement and Professional Fallibility

It will be useful to put professional judgement into a context. Eraut (1994:155) notes that there is a tendency to treat professional judgements as infallible though there is considerable evidence that they are not. In his view professionals are not only equally susceptible to the common weaknesses in human judgement but they also allow their expertise to decay. Mathematical models of decision making have been constructed over the last 100 years by contributors such as Wald (1939), Lehmann (1950), Ramsey (1926) and Savage (1961). The models are statistical and are used in economic predictions, computer science and game theory. They rely essentially on the idea that decisions can be reduced to the probability of a particular course of action resulting in a particular outcome. The models distinguish between normative decisions, i.e. how decisions should be made and descriptive decisions that report how decisions are actually made. The principal weakness in the mathematical modelling of decisions is that humans are regularly seen making decisions and exhibiting behaviours that contradict the predictions made by the models. (Hammerstein & Stevens 2012:2).

If the view is taken that decisions can be made flawlessly and consistently by algorithm it may be tempting to think that the heuristic judgements which do not comply neatly with rational mathematical models must somehow be flawed. It is reasonable to be sceptical of any such claim. Heuristic cognitive processes have evolved over millennia and the fact that we are so successful as a species due to our cognitive faculty must render questionable any tacit assumption that human judgement is inherently seriously flawed. Differentiating between appropriate and successful judgements and those which consistently follow models of predictability is one way of addressing this dilemma. A successful judgement is one which is correct and assures the inclusive fitness of the judge within the temporal and circumstantial frame within which it is made. Given the variation of all possible environments in which judgements are made, it is likely that only flexible and variable judgements will be favoured by natural selection and not logical and consistent ones. (Hammerstein and Stevens 2012:3)

2.3 Human Cognition and Judgement

2.3.1 Cognitive Bias in Judgement

The flexibility or apparent unpredictability in behaviours arise due to evolved cognitive processes which are subject to certain kinds of bias. They include issues such as risk taking when the prediction favours risk avoidance, seeking immediate rewards in preference to waiting or placing a high value on possessions when trade offers a better deal. Seminal work by Tversky and Khaneman (1974) on judgement and uncertainty in a study of cognitive bias in expert decision making found that experts and laypersons alike were susceptible to three main categories of cognitive bias which are namely susceptibility to the bias in which losses are considered more prominent than gains, focussing more on changes to a utility than the absolute value of the utility itself and estimations of probability which are severely affected by the tendency to place a premium on the first piece of information they are presented with. These three factors contribute to experts making serious errors of judgement and are likely to be one of the principal causes of expert fallibility.

These propositions suggest that the way information is presented in the initial stages of a problem based learning environment may affect the way judgement is exercised in problem space definition and later in problem space re-alignment and modification. Fallibility occurs in failing to define the problem space correctly and in weighing the effects of the salient features versus the most probable explanation and underestimating the cost of errors. In 'Thinking, Fast and Slow' Khaneman (2011) provided a thorough discourse on rational and heuristic thinking in which he compares both of cognitive systems and their effects on decision making in various social and work contexts. Heuristic judgements are a useful class of judgements though they are often not based on reason or evidence and to take account of these is rather different. A heuristic judgement may be thought of as sound if it produces a decision or action that is demonstrably better than a decision made by sheer chance or random selection. Heuristic judgements often occur when information is incomplete or evidence is uncertain they are nearly always subject to emotions and values and so in some circumstances heuristic judgements may be the expression of richer human experience.

2.3.2 Decoupled Cognition, Reflection and Planning

Eraut (1974:152) argued that a significant proportion of professional daily practice is actually routine and does not necessitate any great degree of consideration. It is the occurrence of the non-routine which necessitates due consideration and even then there is the tendency to rely on tried and tested methods of resolution rather than engage in more efficient or innovative methods of problem solving. More pertinently to a discussion of professional judgement in engineering is how experts learn to cope with risk and uncertainty and how they exercise judgement in the absence of information. In routine daily practice, reflection in action is largely implicit or informal rather than purposeful or carried out in formal circumstances. Coping with uncertainty is stressful and one of the ways in which reflection and informal planning activity occur in these situations is through a phenomenon known as decoupled cognition. Humans depend greatly on information and cooperation from other humans and decoupled cognition is an evolved cognitive mechanism crucial to psychological well being. Decoupled cognition is the ability to have a conversation with ourselves which is decoupled from real time. Humans spend an enormous amount of time thinking about things which are spatially and temporally removed from the here and now. Whenever we participate in activities like listening to a lecture, watching a film or sitting in a meeting we simultaneously run scenarios in our mind of conversations we had earlier or other exchanges that we may have in the future (Thompson 2011:54).

To evaluate information provided by others and construct networks of information to make decisions, humans can with decoupled cognition, infer circumstances that are predicated entirely on their own imaginings. Decoupled cognition is also necessary to be able to produce external representations. During this cognition an idea may present itself following a period of reminiscence that enables negotiation of a particularly difficult part of the problem space whereas proximity and concerted thinking in the problem space proved ineffective (Boyer 2002). Decoupled cognition plays an important role in both reflective mental activity and forward planning and because decoupled cognitions contribute to the nature of our systems of belief they can have a significant effect on the quality of any judgements made.

2.3.3 Reflective Judgement in Action

Despite the likelihood that negotiating a problem space will have expended a great deal of time and effort and generated a number of errors or re-iterations time is rarely allocated in professional practice to reflect objectively upon action in a formal sense. Where a project or problem is concluded with a sense of satisfaction then a successful conclusion becomes the justification that everything went well and any sort of evaluation would only be a statement of the obvious. This satisfaction with the outcome is fine if that's all that matters but it is a fallacy in reasoning to use it as a measure of process. It underestimates the effect of sheer good fortune and promotes an illusion of skilled handling and management (Khaneman 2011:216). Good outcomes are not necessarily the product of good processes and reflecting on the validity or quality of an outcome is not equivalent to reflecting on the processes that produced it. Reflection is most likely to occur when there is a sense of failure or that something unexpected and deleterious has occurred. In such reflections hindsight bias and judgements of instrumentality occur.

In considering whether or not reflective practice is necessary, Lipman (2003:15) makes the point that unreflective practices have often been considered irrational and even potentially dangerous but does not agree that they are. In his view customs and traditions viz legacy activities which are carried out and commonly, without considering any utilitarian value or scientific merit are perpetuated in given cultural contexts and as long as that context remains unchanged there is no need to question the validity of the practice. Developing reflective practices on their own may not even result in changes to traditions even when they are burdensome or tyrannical. Changes come from reflective practices that involve sound judgements and the evaluation of reasons.

According to Eraut 1994:107), in models of experiential learning there is a tendency to assume that learners will reflect on their experiences but whether this happens at all depends very much on the temperament and inclination of the learner. He does not discuss whether reflection is supposed to be directed at the quality of the outcome or the procedures involved in reaching the outcome though it is clear to me that it should be directed at both. Reflection is a process of judgement and one of judging relationships, dependencies, proximate and ultimate causation between the elements of the problem space. Reflective thinking is also an awareness of the assumptions that are made in reasoning and the implications of decisions. It involves consciousness and cognisance of the reasons and evidence that support its conclusions and takes into account its own methodology, its own procedures and its own perspective (Lipman 2003:22&26).

There have been initiatives to develop and integrate reflective practices into undergraduate programmes using portfolios. An Integrated Engineering Degree Programme (IEDP) was successfully pioneered at Sheffield Hallam University consequent to government proposals for undergraduate curricula to develop professional skills in learners (Bramhall et al 2012). Innovatively structured around a fictional company model the portfolio was a significant part of the assessed content. There is a tendency to forget the evolution and process and focus on objectives and so reflective practices often prove difficult to implement. In a study on the use of portfolios in the IEDP by Bramhall et al (2012).The students objected to investing additional effort but were able to record achievements from multi-disciplinary projects.

Reflective practice has to be an inquiry into whether the various propositions and factors comprising the problem space were correctly identified and that appropriate and optimally fit decisions were made in solving the problem. Given the complexity of the problem space in large engineering projects reflection may only amount to an approximation or sense that what transpired was or was not successful. The capacity to make sound judgements is the ability to use heuristic strategies to identify an appropriate problem space and to be able to discern the organisation and relationships between domain specific knowledge and the complex holistic issues that comprise the problem space in order to arrive at an appropriate solution. The human cognitive processes involved in decision making and the complex environment in which they are exercised render their measurement at least difficult and in some cases impossible. It is reasonable to proceed however on the assumption that making sound judgements is a cognitive faculty that can be improved in an environment conducive to exercising it and by reflecting upon its processes and outputs.

2.4 Educational Frameworks in Engineering

2.4.1 Activity Led Learning for Engineering Education

The term ALL is defined within the Faculty of Engineering and Computing at Coventry University to define a range of approaches in project based learning which places learning in a real world context and is self directed by the learner.

> " ALL is a pedagogic approach in which the activity is the focal point of the learning experience and the tutor acts as a facilitator. An activity is a problem, project, scenario, case study, research question or similar in a classroom, work based, laboratory based or other appropriate setting and for which a range of solutions or responses are appropriate. Activities may cross subject boundaries, as activities within professional practice often do. Activity Led Learning requires a self directed inquiry or research like process in which the individual learner, or team of learners, seek and apply relevant knowledge, skilful practices, understanding and resources (personal and physical) relevant to the activity domain to achieve appropriate learning outcome(s) or intention(s). To be appropriate, the learning outcomes or intentions must be consistent with the aims, outcomes and

> intentions of the programme of study with which the student is engaged." (Wilson-Medhurst et al 2008).

This is the current definition of ALL in use at Coventry University and is based on work by Wilson-Medhurst (2010:1) and earlier work of educational researchers such as Barrows and Tamblyn (1980) Barnett and Coate (2005) and Savin-Baden(2000). In ALL the learning experience is based on activity with the learners at the centre of a community of inquiry facilitated by the tutor. The problem and activity are placed before knowledge transfer and the learner is placed in a challenging learning environment to make connections between what they experience through action, knowledge, critical thinking and understanding.

From the definition, ALL as a paradigm is supported by constructivist theory and the premise that knowledge is constructed by the learner rather than transferred from a tutor. The definition provides that learners may be situated in learning environments in which they learn as individuals or as members of communities of inquiry (Lipman 2003:20) or practice (Wenger 2012:1) in interdisciplinary contexts. According to Liu & Matthews (2005:387) the proposition of individual knowledge construction is considered to stem from the work of Piaget and emphasises the centrality of the learner in a process of discovery. On the other hand the social constructivist tradition of Vygotsky (1978) holds that the learner learns by participation in a social environment or community and emphasises the importance of social context and culture in cognitive development. Social interaction is considered central to development whereas in individual constructivism the social interaction is held to be a stimulus that drives the individual to construct knowledge (Liu & Matthews 2005:388). It could be argued that ALL is located in both Piagetian and Vygotskyan constructivist theory. ALL environments frequently involve learners participating in team projects and accounts of their learning may be considered to be a social learning system or community of practice or inquiry. Wenger (2012:1) acknowledges that the concepts of communities of practice and social learning systems are based on work by other theorists such as Bourdieu (1977); Vygotsky (1978); Foucault (1980); Giddens (1984); and Lave (1998); to account for the social aspect of learning. The similarities between communities of practice and ALL can be seen in the conceptual similarities between the activities in the ALL definition and the following quotation from Wenger (2012:1) on communities of practice and social learning systems.

> “Engagement in social contexts involves a dual process of meaning making. On the one hand we engage directly in activities, conversations, reflections, and other forms of personal participation in social life. On the other hand we produce physical and conceptual artefacts – words, tools, concepts methods, stories, documents, links to resources, and other forms of reification – that reflect our shared experience and around which we organise our participation.”

In this thesis in order to differentiate between the concept of learning in a social system such as work or other professional context and social learning in the learning environment of ALL I refer to the former as communities of practice and the latter as a communities of inquiry (Lipman 2003:20,21). They are in many ways, similar by virtue of the fact that both are human constructs that rely on similar social interaction mechanisms and cognitions. I will say however that there is at least one significant difference. A community of practice is by definition a community in which practices are learnt and in which there is likely to be an expectation of compliance with current practice (Lipman 2003:96). A community of inquiry however is one in which current practice can be acquired, adapted or ameliorated by being open to question, a position supported by Lipman (2003:178). There may be a range of communities between these two cases. Handley et al (2006:642) compare situated learning theory and communities of practice to Vygotsky’s theory on socialisation (Vygotsky 1978). They posit that Vygotsky predicts communities reproduce smoothly over time whereas in their view communities of practice admit the possibility of variance and even conflict because the participants bring personal histories to the community. Participation in the community is considered to be the core phenomena in situated learning but is not merely a physical action. Participation is being able to negotiate meaning and mutual recognition (Handley et al 2006: 643) Whilst participation is considered fundamental in communities of practice and inquiry, levels of participation between community members vary. Lipman (2003:95,96) for example discusses the diversity and participation of communities of enquiry and Handley et al (2006:44) cite Wenger's (1998) view that participation takes various forms so that there is a continuum between peripheral and full participation. Some individuals may not seek or be able to achieve full participation. Strong community participants may impede or discourage the full participation of new community entrants particularly if their innovative practices pose a threat to the community or the knowledge in which they have investment.

In contrast, traditional didactic approaches are predicated on tutor authority and expertise and that all learners start from the roughly the same point, possess similar aptitudes and learning needs. Didacticism focuses on the instruction of subject content and assumes the tutor can summarise a body of knowledge selected for the learners who are largely passive participants. There is no expectation of inquiry on behalf of the learner. ALL on the other hand permits tutor fallibility, diversity among the learners, opportunities to explore, seek and apply knowledge to develop flexible networks of knowledge and to inquire for deeper understanding.

ALL is also considered to improve student retention and engagement. (Green and Wilson-Medhurst 2009). A study by Lambert and Harrison (2012) on an ALL implementation at Coventry University found that the students subsequently surveyed gave no positive responses relating to learner satisfaction from the first year aerospace students who had engaged in the ALL experience. Other aspects on self-confidence, problem solving and analytical and critical abilities that are considered fundamental attributes of ALL also score negatively. The study was on data from a single cohort and may be extreme. First year students encountering ALL for the first time may also find the experience different to the expectations they have from education in schools and are reacting to an experience that is novel and challenging. The value of project work in multi-disciplinary teams to develop 'wicked' competences was reported in a conference paper by Wilson-Medhurst et al (2012) on a series of PjBL initiatives at Sheffield Hallam University, Loughborough University and London Southbank University. The projects stressed team working, communication and reflective practices across different discipline boundaries. The initiatives were considered to have higher levels of student engagement but that they were more likely to see the benefit of this type of initiative as the memories of the experiences were re-activated at later stages in their studies. This finding is indicative of the complex nature of learning and the potential of ALL like activities to motivate and facilitate deep learning.

2.4.2 The Scope of ALL Environments

ALL could involve various kinds of learning activity e.g. researching information, presenting findings, writing reports and papers, practical constructive projects, problem based learning, project based learning, either individually or in teams and in real or simulated situations. All of these activities will feature to some extent, some or all of the following mental acts: creativity, deliberation, organising knowledge, identifying relationships, critical thinking, judgement, discussion and information sharing, reflection, modelling, creating schemata, memorising and recording. Kolb (1984:197) sets out his vision of an effective learning environment in which the learner needs to be engaged in a combination of several modes of learning. The environment should provide opportunities for the learner to experience concrete events, conceptualise abstractions, observe and appreciate and take action in situations with real consequences. Kolb does not talk of judgements but it seems clear that the opportunities he refers to involve the need to exercise judgement. These mental acts are not necessarily dependent on action. We can for instance make a judgement about something creative without having created it and yet if we engage in creating something then we will inevitably make a judgement albeit a perfunctory one as to how suitable or aesthetic it is, whether it is personally satisfying and we may even reflect on how it might have been improved if an alternative course had been followed. All of which involve making some form of judgement. Similarly information sharing and discussion are not consequences of creativity or judgement though if we engage in it and receive peer critique even in an informal and unstructured way we will reflect upon the exchange of values and our creativeness and judgements may be altered. Finally we could add to these the development of self-awareness and making judgements about one's own capabilities. The learner may not be engaged explicitly in thinking about how well they perform a certain task or understand particular issues but a consequence of developing systems of knowledge and models of reality will impact upon the way they view themselves and their position in relationship to that body of knowledge.

2.4.3 Activity Led Learning through Problems and Projects

This section considers Problem Based Learning (PBL) or Project Based Learning or (PjBL) as an Activity Led Learning environment for developing judgement capacity. There is growing interest in the use of PBL and PjBL in engineering higher education and positive reports of its benefits in learning and student retention have been made by higher education practitioners, Mills & Treagust (2003), Schmidt et al (2006), Hmelo-Silver, Duncan & Chinn (2007) and Gattie et al (2011). The value of problem solving as a driver of human action is succinctly put by Karl Popper;

> *"my subject does not exist because subject matters in general do not exist. There are no subject matters; no branches of learning - or, rather, of inquiry: there are only problems and the urge to solve them" (Popper: 1983)*

The terms Problem Based Learning or Project Based Learning have often been used interchangeably by authors and so when we read of one or the other there is sometimes no sense of what is actually meant by the two terms. Graham (2009:1) uses the definition provided by Prince and Felder (2006).

> *"Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome."*

Dworkin (1959:122) quotes John Dewey whose ideas on project work were stated thus;

> *"The test of a good project is whether it is sufficiently full and complex to demand a variety of responses from different learners and permit each to go at it and make their contribution in a way which is characteristic of themselves. The further test or mark of a good activity............. is that it have a sufficiently long time span so that a series of endeavours and explorations are involved in it."*

ALL makes no distinction and encompasses activities of a diverse nature and includes ideas that can be expressed as both projects and problems that are either short or long in duration and may be experienced in real or simulated environments. The principle is that whatever the context it is applied in, by definition the activity of problem solving in ALL is anterior to knowledge transfer. This suggests that ALL in its strictest interpretation is a minimally supported paradigm, where given the objective, even the definition initial problem space should be down to the intentionality, bounded rationality and deliberation of the learner. It is in that problem space that the learner discovers knowledge and creates the networks of knowledge and analogies on which they exercise judgement.

2.4.4 Cognition and Problem Based Learning

There are however practitioners who do not find favour with PBL and reject the claims made for it in preference for a direct didacticism and the observation-reflective mode of the formal lecture. Kirschner, Sweller & Clark (2006:75&76) for example, considered experiential learning, inquiry led learning, PBL and constructivist learning etc. as similar and ineffective pedagogic approaches. Their objection is predicated on the assumption that these learning strategies are 'minimally guided' approaches which are not supported by models of human cognition and particularly when the limitations of working memory are considered. Their stance is clearly in favour of directed axiomatic learning and their fundamental argument is that according to cognitive load theory, working memory is very small and overloading it with information seeking and schemata construction in addition to subject content is not conducive to effective learning. The learner or that which is learnt is not clearly defined within their paper and their argument is predicated on work by Chase and Simon (1973) which examined expert recall of chess game scenarios. They further cite Miller (1956) and Sweller (1988), on the limitations of working memory. Such arguments ignore the effect of discussion on learning, schemata development and memorising information (Wolfe & Mienko, 2007) and that human cognitive architecture is evolved to learn efficiently by discerning patterns in poorly structured, unbounded and ill-defined environments where variables and rules are uncertain. Kareev (2012:169) further makes a compelling argument that the small data capacity of short term working memory far from being a hindrance to learning is actually a successful evolutionary cognitive adaptation. Dealing with very small sample sizes produces a cognitive bias where correlations seem much more significant than they actually are and so the environment appears to be more regular. This bias enables the recognition of causal patterns and promotes mechanisms for exploration.

Decisions based on limited information result in variation and in situations where unpredictability is an advantage, consistency in successive decisions is undesirable. The fact that individuals do not correct for the cognitive bias suggests it is a necessary strategy even though it will lead to situations where correlations are perceived where non actually exist. Where cognitive mechanisms compel the individual to think and consider problems which are here and now, the individual is more sensitive to small environmental changes, avoids the possibility of being overwhelmed by past experiences and is driven by a desire to seek knowledge. Hmelo-Silver, Duncan & Chinn (2007) published a more critical and emphatic response to Kirschner, Sweller and Clark which declared their reasoning to be flawed. They presented further evidence that problem based learning (PBL) and inquiry learning (IL), which they consider to be so similar as to be mostly indistinguishable are not minimally guided paradigms but in fact are supported by what they refer to as 'scaffolding' which may be due to direct tutor intervention or more commonly is implicit and due to the environment generated as the inquiry or problem solving evolves toward the solution. Hmelo-Silver, Duncan & Chinn (2007:101) cited Schwartz and Bransford's (1998) hypothetico-deductive PBL model in which students were set a problem to analyse and explain some data and then given a lecture afterwards. Their analysis demonstrated that students previously engaged in the problem solving activity were subsequently better able to synthesize information from the lecture. They also rely on the argument that implicit cognitive load is reduced because tutor intervention can effectively guide the student's definition of the problem space by reducing the number of solution options available to them. In summarising their argument, they introduce the idea that the 'scaffolding' serves to both provide opportunity to interact with complex problems and also assists the learner to define the bounds of the problem space thus inhibiting tendencies to adopt inappropriate or inefficient methods. I have to say that while this may expedite a solution it is potentially counter-productive in a community of inquiry that seeks to exercise the judgement of the learner. Where the tutor intervenes 'in an expert capacity' to reduce the problem space they are merely teaching the student to think like themselves instead of encouraging them to develop their own criticality. It may be that making judgements in professional competence, the skill in judging the relevant operators is the most important part of problem solving.

The following discussion on bounded rationality is illustrative of this concept. The term bounded rationality was coined by Herbert Simon (1957) in 'Models of Man'. It is an expression of the idea that decision making is constrained by time and the availability of information and also by the cognitive processes of the mind to reduce the problem to manageable proportions. The concept came about as an alternative to the mathematical modelling that had become prevalent in professional decision making particularly in economics and some branches of engineering. Despite the heuristic nature of the bounded rationality concept, Simon took the view that this optimisation was a completely rational process in decision making though perfect rationality was infeasible due to the finite computational resources that make them. Simon posited there were two but related cognitive archetypes in making judgements and decisions. One of these he calls a satisficer (a portmanteau from satisfy and suffice) who resolves a problem with a solution that is just good enough to meet the objectives. The other he called a maximiser. This type considers their options and alternatives with greater care, and take longer to reach a decision. He opined that maximisers are more likely to regret their decisions. He concluded this was due to the possibility that they were more capable of judging and recognising their decisions as sub-optimal. There may be other factors, for example the satisficer may be better equipped psychologically to cope with uncertainty and marginality when they reach a decision.

The ability to reduce a complex problem space to manageable proportions requires some skill. Without this heuristic judgement in sorting the relevant from the irrelevant, problem solving cannot be efficient, the problem space would be over philosophised and cluttered with the extraneous or over simplified and lacking important details. Learners need to acquire skills to reduce problem spaces appropriately. They are unlikely to do this unless they are provided with the opportunities in practising the necessary skills in judgement and without the guidance to reflect on those judgements. In summary the limitations of memory cannot be a basis for asserting that PBL is ineffective, on the contrary, the need to make efficient reductions in problem spaces to cope with the limitations of short term memory may be the single most important factor that determines the effectiveness of activity led environments like PBL and PjBL as pedagogic approaches.

2.4.5 Solving Problems & Learning through Ill-defined Environments

That learning is better based on the provision of rules and structures is open to challenges. Lipman (2003:13) gives the example of the language learning by infants, in which nothing is prescribed but the environment provokes inquisition and reflection. Infants learn the fundamental skills and nuances of their language in a few years without the benefit of grammar, note taking or dedicated lessons. They learn by inferring the necessary structures from experiences and events. While Lipman's thinking appears to be focussed on experiential learning in school children, there is no suggestion that human cognitive architecture changes in adulthood in a way which makes those experiential learning mechanisms inefficient or redundant in adults.

On the contrary, both Lipman (2003:13) and Dewey (1938:22) make a strong case for the benefits of continuity and creating an explorative learning environment. They both expressed concerns that the structure typical of timetabled school curricular are discontinuous and impose a uniformity and structure on learning that is unexciting, dis-incentivising and potentially impairing of inventiveness and curiosity.

In higher education, Gattie et al (2011:526) make similar claims regarding the focus on direct instruction of the content inherent in engineering courses which they claim may even impair the student's ability to develop skills in thinking across inter-related knowledge domains in complex and unbounded engineering problems. Kirschner, Sweller & Clark made no distinction between various forms of experiential learning which they claim are pedagogically equivalent and in consequence do not consider whether they are distinct approaches each of which may be appropriate to different subject domains or the requirements of different professional practice. The tentative response of Schmidt et al (2007) was to argue that direct instruction necessarily assumes that all students bring the same experiences and have the same instructional needs, whereas PBL enables a tutor to judiciously adapt guidance for particular circumstances and is therefore supported by models of human cognition. Schmidt et al in the same paper also discuss cognitive load theory in detail and compares it with the methodology of PBL to demonstrate that PBL is not minimally guided and does not result in intrinsic cognitive overload of the learner. PBL can be carefully designed to provide an explorative environment which draws upon previous knowledge and schemata and permits appropriate intervention by the tutor to reduce cognitive loading. The authors state that Kirschner, Sweller and Clark (2006:79&80), were selective in their examples of PBL and ignored evidence in favour of problem based approaches. They provide examples from medical education, concluding that team work is an essential component in PBL to reduce cognitive load. The central premise of Schmidt et al (2007) is that PBL paradigms are not minimally guided and do not conflict with models of human cognition. They described a very structured approach to PBL with the need to train students in team working prior to the activity and careful tutor interventions. Whether effective team working can be so prescribed is debatable. Schmidt et al also discuss examples of PBL in which the predominant case for PBL is to invoke prior individual or collaborative knowledge to define the problem space and develop new information. The case studies they refer to are drawn from biology and medicine and they make no mention however of the role of reflection in the learning process.

A paper by Mills and Treagust (2003) discusses the necessity of moving from didactic to student centred teaching approaches in engineering education and compares the suitability of PBL and Project Base Learning paradigms. They attempt to demonstrate that there is a definitive dichotomy between PBL or Project based learning but later cite Kolmos (1996) who considers that the boundary is blurred and that variations in practice between different institutions are variously called PBL or project based learning (PjBL) which may depend on the view of particular practitioners. Mills and Treagust (2003) do not favour PBL as a whole solution and in agreement with Gattie et al (2011:522) conclude that PBL is difficult to implement in course curricula and only occurs where individual lecturers are inclined to it. They raise concerns that most evaluations of PBL initiatives are entirely phenomenological studies by open-ended student questionnaire though many of the outcomes that PBL is thought to generate are difficult to measure. In consequence however, they make the reasonable assumption that not all the outcomes can be clearly attributed to the initiative and may arise from other unidentified efforts directed at skills development. Mills and Treagust (2003:7) state that engineering education is largely axiomatic and the key principles must be acquired in a particular order. Traditional approaches may certainly be viewed this way and in their opinion this assumption makes PBL less likely to be effective as a teaching approach to develop the correct skills and this is in part due to its constructivist nature. Despite the potential issues in distinguishing between PBL and PjBL and given the fact that the latter is also constructivist in nature, Mills and Treagust (2003:10) appear to favour a project based learning approach. They provide evidence from work at Aalborg University and how their graduates are potentially more employable through better developed team and communication skills and ability to carry out large projects.

2.4.6 Meta-Competencies

While there remain debates about the most appropriate way to develop holistic skills there appears to be a convergence on the need for students to develop the capacity for judgement and particularly being able to make correct judgements about complex problem domains. The importance of developing skills in appropriate problem space definition is seen as central to the development of professional judgement capacity by Gattie et al (2011:522). They posit that engineering practice in the 21st century is becoming recognised as a complex holistic knowledge domain in which engineering problems are no longer soluble purely by recourse to technological knowledge. While acknowledging that mathematical and scientific knowledge are appropriate to the well defined and closed problem spaces, problems encountered in real professional practice are comprised of complex and often fundamentally distinct interactions between a whole range of human, socio-economic, legal and environmental issues. Their stance is however quite balanced, whilst they opined that the lack of opportunity for debate in purely mathematical and scientific fact may lead to students graduating with little experience of the holistic social construct, they also express concern that students wholly tutored in discipline-based learning environments may fail to see that mathematics and science has an important role in contributing to the solution of complex problem domains. Gattie et al hypothesised that in arriving at an appropriate solution to an engineering problem the learner will have made a judgement as to which technical knowledge is required and also which broader holistic issues impact upon the solution. Fig.1 adapted from Gattie et al represents the dialectic between technical and holistic aspects in an engineering problem..

Mapping the technical domain against the holistic domain it is possible to envisage parts of the problem space where solutions to a problem could be appropriate in the use of technical knowledge and sufficient in the influence and consideration of holistic issues. Appropriate solutions could also be complicated or simple in both regards. In the one extreme however, the solution may be technically insufficient but excessive consideration is given to holistic influences or in the other where the solution has complex technical demands but there is no consideration given to potential holistic influences. Gattie et al (2011:527) advocate that a systems approach should encourage the development of recognising errors and failures in procedure through error generation and correction and positive feedback on reflective learning. Their main premise is that trying to change engineering education at the course level to give students holistic skills development is impractical.

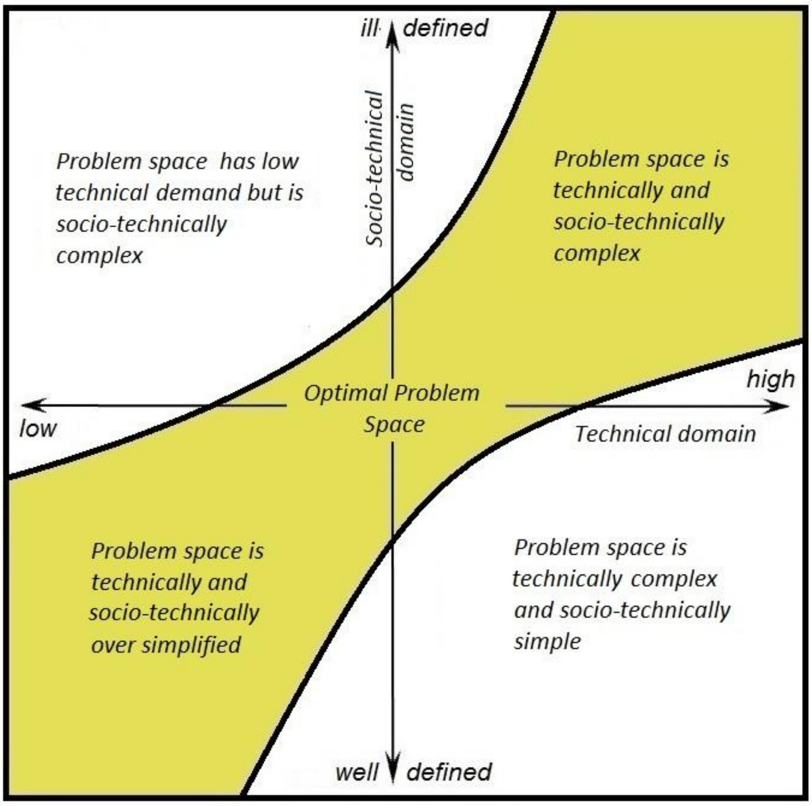

Fig.1 Engineering Problem Space

Without relying on institutional difficulties which have been put forward by previous authors they proceed to demonstrate how typical course level attributes create problems in holistic thinking which they contend would be most effectively remedied by embedding changes at a systems level. They conclude by explaining a pedagogic approach in which students bring domain specific knowledge from subject centred classes into a project based learning environment in order to maintain technical rigour but provide them with opportunity to practice solving ill-defined, otherwise known as 'wicked' problems in order to develop a broader understanding of complex systems.

2.5 The Nature of Judgement

2.5.1 Assumptions about Knowledge

Judgement is possibly the most important mental act in cognitive processes. It is possible however to apprehend and even think without making any kind of judgement. We can be acquainted with all the aspects of a proposition or argument without ever making any judgements as to its validity, worth or its appropriateness (Stout 1896)

(Romdenh-Romluc 2011:57). It is commonplace however to make judgements about the state of things we experience. Without judgement, decisions cannot be made and there cannot be deliberate action on experience and thus judgement is more than thinking, it is a transaction between the sentient and that which is experienced which results in a state of altered consciousness. Not all actions result from conscious and deliberate judgements, and judgements are more than apprehension and awareness. Our attention to an event or experience may be quite incidental and not necessarily due to any particular interest. For example we may be entirely absorbed by a television drama and yet become suddenly aware that a domestic spider has scurried out from under the sofa. Any moving objects alert us to sudden disturbances which we are compelled to investigate. The urge is irresistible, successful organisms must react quickly, cautiously and adaptively to novel stimuli and no conscious decision is ever brought into play (Hammerstein & Stevens 2012 :277).

Judgements can be unintentional mental acts in the course of everyday action and in many cases they may be trivial and inconsequential, relating to everyday occurrences or thoughts. In this we might include the judgement that a cup coffee is not as good as the last one, that a bouquet of flowers are particularly beautiful, or that a particular purchase was, in hindsight, expensive etc. Despite the banality of some judgements, they may have potentially serious consequences if they are not sound. For example when driving, the failure to judge speed or distance appropriately and in certain contexts could be fatal, or the poor inclination and stability of a ladder before we ascend it could result in injury. Whether judgements of any kind are made either subconsciously or consciously, the individual relies on certain assumptions about knowledge.

One does not need to have recourse to any particular wisdom to make a judgement but there are underlying axioms about the veracity of knowledge and truth and how we know things. In direct experience an individual witness may for example say, "I have observed it and so it must be true". Or conversely, "I saw nothing so it cannot be true". In these cases the epistemic assumption is that knowledge exists absolutely and can be acquired by observation. Neither of the statements is particularly sound, in the first place visual acuity in humans is limited to the foveal region of the eye and persons are prone to inattention in observation. The study by Simons and Chabris (1999) on sustained inattentional blindness for dynamic events showed that approximately 50%

of witnesses are unaware of significant visual disturbances when they are pre-occupied in observing a particular sequence of events.

Epistemic assumptions may also rely on the argument of authority. " It was reported by this authority that.....", or "I read it in a newspaper so it must be true". This is one of a number of logical arguments in inductive reasoning (*argumentum ad auctoritatem*) which is often applied fallaciously. Here the epistemic assumption is that knowledge is absolutely certain and can be obtained directly from perception or figures of authority. In reasoned formal rationality the epistemic assumptions are that knowledge is uncertain, context bound, characteristic of individuals or groups, constructed, interpretative and the outcome of evaluated reasoned inquiry (King and Kitchener 1994). A number of factors are also known to promote variations in decision making by individuals and include factors like cognitive ability, life span changes, working memory, mood, personality and noise (Brown et al 2012: 227-236). Because this study deals with the development of judgement capacity in adolescents who are engaged in some form of professional development it is necessary to consider briefly the nature of cognitive development at that age group. Frame (2013:201-205) discusses the development of the brain and cognitive functions from childhood to maturity and refers to this process as 'arboration' in which after rapid growth during childhood, neural pathways that are exercised, are consolidated towards puberty whereas redundant pathways are reduced. This process begins at adolescence and does not complete in most people until their mid to late twenties. It suggests that particular aspects of cognitive function can be developed by interventions that exercise the cognitive mechanisms associated with them. It also suggests that if intervention is left too late then the opportunity to develop particular characteristics is lost.

Frame (2013:203) cites the work by Yurgelun-Todd (2002) who measured brain activity in adolescents by Functional Magnetic Resonance Imaging and reported that activity in the amygdala and frontal cortex is correlated with age. The former being more pronounced in young adolescents and the latter in those near the age of majority. These findings are often cited as an indication of the difference between child and adult brains and the onset of reasoning. Lack of risk aversion and unawareness of consequence is attributed to the incomplete development of the frontal cortex. Other researchers do not think brain development can entirely account for lack of judgement in this age group. Frame (2013:204) cites Epstein (2007) who considered social factors to be formative. Epstein posited that reckless behaviour by adolescents is a social construct in modern industrialised societies where teenagers associate with other teenagers and have low exposure to adult models. He points out that in pre-industrial societies teenagers associate much more with adults and the incidence of adolescent behaviours are much lower. It has to be said however, this does not imply they are better at making judgements. It may indicate behavioural adaptation by imitation or suppression by the proximity to authority.

Adolescent cognitive development ideas has implications for the development of an educational programme to develop judgement capacity in learners. Although adolescents are known to be poor at making judgements they are at a stage in their cognitive development when it is probably optimal to introduce them to both the concepts of judgement and the exertion of judgement in controlled educational settings. By this they can be meaningfully engaged in dialogue about their decisions in the context of adult and professional expectations.

2.5.2 The Complexity of Judgement

In professional environments there are conditions in which judgements are made can be very complex. In such circumstances the judgements themselves and the consequences of any decisions that result from them are far from trivial. Judgements in this category have to be made with great consideration and the person making them should apply reason and logic to the propositions and arguments (the problem space) in order that the judgements are sound. Lipman (2003:96) refers to this prejudgement thinking as ‘deliberation’ a process of weighing of the reasons and alternatives which takes place before a judgement is made. I will say that the deliberations are also judgemental acts of a kind and Lipman (2003:281-288) later goes onto explain in his analysis of types of judgement that there are ‘culminating judgements’ and 'mediating judgements'. Table 1. below shows the examples of judgements given by Lipman

Table 1. Taxonomy of Judgements

Judgement	Example
Identity	The same as or equal to e.g. mathematical equations
difference	Discriminations, perceptual, logical, conceptual, material

similarity	Simple , primitive likeness or resemblance
membership	Classifications, of the same group, species
composition	Is part of or belongs to
Division	The properties of the whole are also properties of the parts
relevance	Il-defined cognition for building arguments, informal fallacies in reasoning are fallacies of relevance. Truth in relevance depends on the number of connections between ideas and their validity.
Analogy	Exact as in ratios or inexact as in 'hands are to arms as feet are to legs'.
inference	When we cannot be sure the truth is preserved the inferential judgement is an induction. When truth is the judgement is a deduction. Inference is a key judgement for extending knowledge.
causality	Statements of cause, causality is considered to be an attribution
appropriateness	Fitness - not rule based but as in purpose, occasion or behaviour
Value	More than, less than
practicality	Application of rules and laws
reference	comparison
translation	The soundness of meaning, that meaning is preserved across different contexts
measurement	Judgement of value by arbitrary scales
factuality	There is sufficient evidence
hypotheticality	Judgement of consequences of action or decision
counterfactuality	Hindsight - what would have happened had an alternative course been enacted
instrumentality	Adjusting means to ends and vice versa.
Intentionality/ agency	The attribution that an act was intentional or an event was due to agency

The distinction between some of the judgements is not always clear, for example composition is a judgement of 'this is part of or belongs to' and judgement of membership is the classification of families and species. I must say they are remarkably similar and wonder whether they are distinct judgements or even if they are distinct cognitive mechanisms. A number of Lipman's judgement categories such as the first six listed in Table 1 are essentially discriminatory. That the discrimination or classification of something may be due to different semantic images or judgements about different attributes does not necessarily imply that the act of judgement is fundamentally different at a cognitive level. For example a judgement of membership of a group is discriminatory and must involve judgements of difference and similarity. It is difficult to see that when these judgements are exercised they are the result of completely different cognitions. There may also be a judgment of value about the degree to which something is similar or dissimilar. Intentionality is an attribution and as such is an entirely heuristic judgement. Causality has also been considered to be an attribution (Rips 2011:77) though in sound and rational judgement of causality there will be mediating rational judgements of factuality.

2.5.3 Perception, Awareness and Judgement

Judgements of discrimination provide useful examples of the cognitions that may be called judgements. We may for example observe two different colours and distinguish the fact that they are different. The phenomenon of perception of the colours red and green is by virtue of their different electromagnetic wavelengths and the photoreceptor cells of the retina that are sensitive to those wavelengths. The experiences of one perception or the other are referred to by the conventions red and green. Is this act the exertion of judgement or is it awareness? If we apply the argument put forward by Stout it is awareness but for Lipman it is a simple judgement. It is therefore necessary to define a boundary where we consider the transition from awareness to judgement. If in the previous act of perception we attach a meaning to it i.e. “safe to move” or “unsafe to move” then reason can act upon the information, exercise judgement and make a decision. There are even in this straightforward process a sequence of several judgements that are made almost simultaneously including difference (colour), analogy (this colour is to ... as that colour is to...) practicality (standard rule red = stop, green = go) inference (safe to move). In this instance it is reasonable to say that knowing the difference between red and green is an integral function in the exertion of judgement. We are no longer simply aware that the two are different, they have become part of substantive rationality.

To make a judgement then we have to say is more than just apprehending and being attentive to something it has to be a definite mental act in which we consciously discriminate between sensory inputs, previous experience and accumulated knowledge, integrate and process the information in order to arrive at a decision. Lipman has however gone to some lengths to map a comprehensive range. Few if any of the examples he gives could be thought of as exact and some of them are altogether quite vague notions. When he speaks of measurement which might be thought of as having a degree of precision he also refers to the arbitrariness of the measurement scales and analogous methods of representing phenomena. Some analogical judgements such as ratios however are exact. The judgement categories which are of particular interest are those which relate to critical thinking. In such cases the conflict and tension between the factual and the emotive present a disjuncture which has to be resolved by the judgement. The judgement of causality is concerned whether actions or phenomena are related and their degree of causal proximity. This judgement is most often associated with the pro hoc ergo propter hoc fallacy in reasoning where unrelated events are seen to be connected by virtue of one event being anterior to another. The judgement of appropriateness is about the quality of the fitness or equitableness of an action or outcome or product. Lipman (2003:284) stated that this judgement is not criterion based but concerns the entire context of the inquiry. When someone is accused of a lack of judgement the accuser is applying a judgement in this category. The judgement of value is comparative and concerned with statements such as more beautiful than, bigger than, better than, worse than, most, least etc. The criteria are often not explicit. The judgement of hypotheticality relates to prediction and the consequences of action or incident and are more than just notions of probability (Lipman 2003:285). The judgement of counter factuality is the facility of hindsight. When we make this judgement we are reflecting on events and actions and judging what the outcome would have been had matters been different. The judgement of factuality can be more than accepting whether something is true or false. Factual judgements, judge whether the evidence is sufficient to warrant that which is being asserted. This judgement is delicate because mediating judgements have to be made on what actually constitutes evidence and how much evidence justifies the claims (Lipman 2003:286).

These judgements often crop up in courts of law and are complicated by rules as to the gathering of evidence, the persons rights and notions of fairness. The judgement of practice relates to recognised and standardised operational procedures and systems. The judgement is made within a framework of criteria on when and how to install or maintain something, harvest something, store something, prosecute someone, heal someone etc. The judgement is guided by routine and ameliorated by custom and precedent. Judgements of reference are judgements of comparison of attribute and whether artefacts correspond with others. A judgement of translation is concerned with whether the meaning of something is integral and unchanged in situations where the context is changing. The judgement of instrumentality is made in adjusting means and ends and is an important concept for the engineer in large social impact projects. Judgements of division are the opposite of judgements about composition. When we state that the properties of the whole entity is also invested in the parts we make a judgement of division. It is a common fallacy to assume that this is always so and attribute behaviours and properties by stereotype (Lipman 2003:287). Judging relevance is not explicit, the judgement is dependent upon the nature of the network of knowledge, the number of connections in the network and the how we weigh the relative importance of those connections. Finally the judgement of inference is used to extend knowledge and the judgement is made when we conclude or predict from applying reason and logic to an inquiry. Inference is inductive when there is no warranty that truth is preserved and deductive when we are sure that it is (Lipman 2003:283).

2.5.4 Toward a Definition of Sound Judgement

It is necessary at this point to define the concept of sound judgement. When we say that a judgement is sound we have exercised a judgement that may involve any of the other judgements with regard to inference, relevance, causality, appropriateness, hypotheticality, practice, fact and instrumentality. For the purposes of this inquiry I define soundness as;

> "In as much as the facts are known, as having the qualities of being correct, equitable, appropriate and reasonable and based on epistemic assumptions which themselves are founded in reason and evidence."

In making any a judgement we have to be aware that our temporal displacement from the act is not so great as to lead us to make a determination that results only from the consideration of current knowledge and mores. In examining all the available evidence and having considered the consequences we must judge appropriateness of an action as being appropriate of that time otherwise we do great injustice to our forbears. That historical incidents are not deemed to be appropriate from the perspective of modern times reflects our advancement of knowledge and secular values and not the value of the action when it was made. From the previous discussion and as a working definition I think this notion of soundness is itself quite reasonable but its weaknesses are that there is not always agreement on facts and evidence and some judgements are made in the absence of knowledge. Experts do not always make judgements and treat evidence the same way and what one expert considers a reasonable inference or deduction and judgement may be contrary to the views of another given the same set of facts. Any act of thinking may leave considerable room for debate about the influence of facts, reason and logic. This fact alone is counter intuitive to any notion that the nature of judgement can be absolute. Frame (2013:131) discusses judgement acumen and opines that bad judgement is the inability to see the consequences of decisions or actions and categorises lack of judgement as due to inexperience, transitory lapse or habitual cluelessness. This view places bad judgement per se firmly in the domain of judgements of hypotheticality and appropriateness (Table 1.) In the context of behaviours this is plausible but in research by Kahan et al (2013) as discussed in 3.1.1, bad judgement can result from systems of belief and cognitive bias (Tversky and Khaneman 1974).

When we are posed with a problem and exercise heuristic judgements to form an initial problem space definition, we make intuitive leaps about the relevance and value of particular phenomena and noumena. In this act we exercise heuristic judgements about whether something is worth exploring or knowing. In the process of making informed judgements we may see that some of the most powerful judgements we make are heavily reliant on intuitive heuristics. Lipman questions the assumption that by adopting initiatives to improve reasoning, people will exercise better judgement or to assume that better judgement results in better decisions and actions (Lipman 2003:274). Given the uncertainty in facts, judgements and rationality it may not be efficient or even possible to educate for absolute reasonableness in behaviours or thinking. An approach that provides the leaner with opportunities to exercise judgement in a diverse situations and enable them to develop habits of action (Dewey 1916) to reflect critically on assessing their judgements for reasonableness may be more useful in developing professional judgement.

Fig 2. Below is an ideogram representing at a fundamental level the epistemic nature of an instance of an exertion of judgement. The intentionality of an individual is constituted of prior knowledge states and experiences, framed by cognitive bias they form our systems of belief. Whenever a disjuncture is encountered or a proposition is cogitated, the presented state of affairs is considered within the limits of currently held knowledge. This consists of previous knowledge states from experience, perception and thought together with the effects of cognitive biases, collectively this constitutes our systems of belief. These are the principal components of everyday judgement. When the judgement is exerted the individual making the judgement intends something about the state of affairs under consideration and undergoes a change of consciousness. That is they either confirm what they believe or change what they believe.

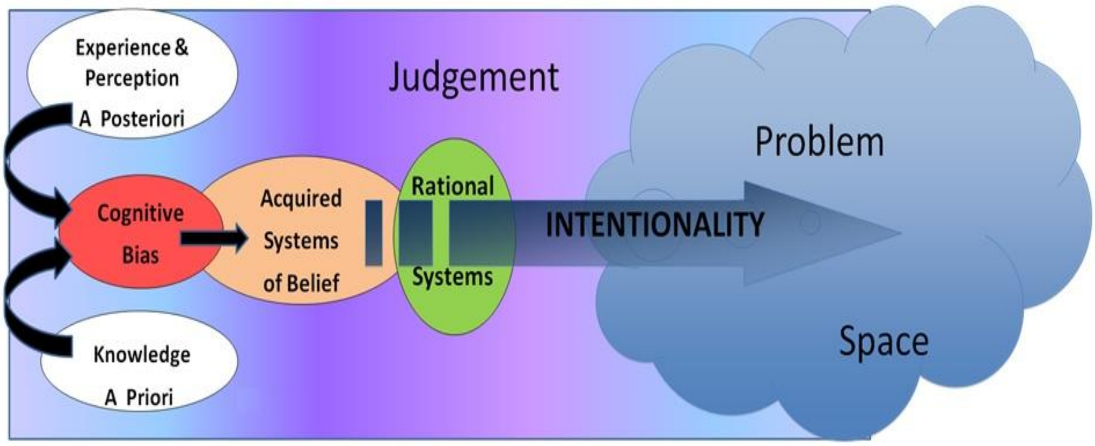

Fig 2. The Exertion of Judgement

Fig 2. From poster presentation 'The Development of Judgement Capacity in Engineering Students' H Igarashi, Engineering Research Symposium Coventry University May 2015.

The professional or individual developed in rational thinking systems may in addition ameliorate judgement by rationality. Thus the intentionality of the thinker forms the problem space, viz they define the problem space by virtue of the knowledge and beliefs they bring to it. Each proposition or disjuncture that subsequently presents to the thinker is treated in the same way so that the process of thinking is multiple reiterations of this process, each iteration changing the consciousness of the thinker in subtle and diverse ways. Sokolowski (2000:99) provides a succinct phenomenological explanation of judgement;

> "A judgment is not there waiting for us to infer its presence rather it is a dimension of presentation a change of mode of presentation that arises when we enter into the propositional attitude by means of a propositional reflection".

3. Conceptual Frameworks

3.1 Methodology.

3.1.1 Background to the Research Methodology

This research is concerned primarily with trying to understand a faculty of human cognition that cannot be directly detected or observed and is therefore resistant to measurement by an empirical methodology. It is worth acknowledging that empirical research into judgement by Kahneman, Slovic & Tversky (1982:4,32,337) has resulted in the development of powerful models to explain the functioning of cognitive architecture and the irrationality and bias inherent in human decision making. By using simple scenarios, based on mathematical problems or queries to which there are verifiable statistical models or evidence, they were able to test the judgements of the test subjects in an objective way by comparing them to rational mathematical models. In psychological studies, the judgements of research subjects are compared with algorithms or mathematical and statistical models to determine rationality. Such an approach lends itself to an empirical methodology where participant reactions are tested experimentally. This study alternatively, examines the diversity in the way judgement is exercised in complex environments that are not standardised models in which ideal judgements can be assessed by a particular metric. This prevents the adoption of an empirical route.

One objection to an empirical approach is that judgements are rarely made in the act of considering a single proposition in isolation from external influences that can be usefully compared to a rational mathematical argument. Within the case studies in this research it can be seen that real time judgements are made against a rich background of complex technical and social constructs and that judgements are influenced quite remarkably by established systems of belief and evolved cognitive biases. Hammerstein and Stevens (2012:3) question the validity of the premise that decision making processes should be consistent and logical. Their view is that natural selection would favour successful rather than consistent outcomes of a process. Consistent decisions would result in predictable outcomes that would be costly in a variable environment in which behavioural flexibility is favoured. Kahan et al (2013) demonstrated the effects of prior belief on cognitive ability in a study of one thousand, one hundred and eleven adults in America. He found that when the subject of a mathematically identical problem was changed from 'new skin rash treatment' to a 'gun control ban', otherwise mathematically competent individuals inaccurately interpreted data in such a way as to avoid conflict with their political views. Other factors are known to influence cognitive performance particularly blood glucose levels. Scholey et al (2001: 585 - 592)

3.1.2 Choice of Methodology

The methodology and research method was chosen to be able to understand the learner's experience of making judgements in ALL. This assumes the necessity to access complex experiences in a learning environment that is too complex to be reduced to simpler statistical models. Moreover the focus of the research concerns an area of human cognition that cannot be measured directly. The research method and research tools are selected and designed to provide original data on the way the faculty of human judgement is exercised in those complex situations. The theoretical arguments that underpin human cognition and human decision-making, and the ontological and epistemological grounds for them are set out herewith.

Scientific method is founded in western philosophy that stems from the latter of two distinct philosophical arguments from Heraclitus and Parminedes (Gray 2009:17-18). The former tradition emphasises 'becoming' and a reality which changes and emerges and the latter tradition which has become the more prominent, on 'being' and a permanent and unchanging reality. Permanency enables the representation of form and phenomena and noema by symbols, words and concepts. This epistemological position validates thinking that is directed at outcomes at the expense of neglecting processes. The idea that symbols and representations of logical, scientific and mathematical enquiry is the source of all authoritative knowledge is known as positivism. The other emergent theoretical perspective from Parminedian ontology is empiricism. This philosophical stance is common in scientific enquiry and holds that all knowledge is derived from and is dependent upon sensory experience (Gray 2009:17-18). Thinking and judgements however are processes that ensure all of our experiences of reality are not permanent and are therefore repeatable (Kolb 1984:26). Studying judgement means having to observe the phenomena of dialogue and action and the transition from one state of affairs to another in order to infer that particular judgements have been exercised. To conduct this study I have opted to use a phenomenological theoretical framework and methodology.

3.1.3 Ontological Background to Phenomenological Enquiry

Phenomenology emphasises both 'being' and 'becoming' and recognises that a kind of experiential permanence is vested in memory that is not immutable but constantly changing. The exact epistemological position of phenomenology has been the subject of debate by its principal proponents. The phenomenological epistemology in this study is based upon the work of Edmund Husserl and Maurice Merleau-Ponty who, influenced by the work of Immanuel Kant, considered empiricism could not account for all of human experience (Kant 1855: 30). From a phenomenological perspective, empiricism had not revealed all that could be known and although agents can be sure of their own experience in Cartesian ontology, the existence or the true nature of the real world is not established beyond doubt. Husserl's phenomenology relates the construction of knowledge to perception and transaction with the outside world to construct meaning (Morphew 2009). His principal objection to scientific inquiry was that its ontological status begins with the experience of observation and rests on the unjustified assumption that what is being inquired into does in fact exist. For Husserl, empiricism and positivism consider consciousness as something detached from the world but subject to its physical laws including that of causation. The difficulty in relying on empiricism to account for all of human experience led Husserl to consider how experiences could be explained without having to accept the apodicity of reality.

3.1.4 Phenomenological Considerations in the Observation of Phenomena

Mainstream Husserlian phenomenology posits that reality and the experience of it can be known only if the observer suspends any presuppositions and preconceptions of what that experience actually is. In Phenomenology, there is the phenomenon of intentionality. When an observer attempts to explain something, assumption, conjecture, generalisation and hypothesising by the observer interfere and change that which is given. The early Husserl attempted to distance phenomenology from this activity. To do this he was convinced of the necessity to perform what he referred to as the Transcendental-Phenomenological Reduction or epoché or more commonly referred to as 'bracketing ' (Romdenh-Romluc 2011: 21). Epoché is the suspension of the natural attitude that the world exists so that experience is contemplated in complete isolation from assumptions about worldly objects. In its strictest interpretation Husserlian phenomenology must only describe what is given and should reject any attempts to explain what is happening in order to understand the true nature of consciousness (Romdenh-Romluc 2011: 5-7).

3.1.5 Phenomenological Issues in this Study

A purely descriptive narrative of the learners' actions and dialogue would only report their interaction with the world from their perspective, it will not enable the understanding of judgements. No observer consciously perceives the judgement of another, we are only given the ‘residues’ of their judgements as their dialogues, decisions and actions. If only the 'residues' that are given are described without any assumption or inference that they result from judgments that were made to assess a state of affairs then all judgements remain latent with respect to the observer. This research therefore has to infer from the 'residues', the very judgments that constructed them during some interaction with the world. I must say at this point that I cannot therefore fully accept Husserl’s strictest position and it will be necessary to show that it is possible to know things without direct experience of them and that we are able to do that with reference to the phenomenal world in itself.

3.2 Ontological and Epistemological Background

3.2.1 Establishing a Phenomenological Ontology

To establish a phenomenological ontology I can rely on two phenomenological proofs that relate knowing to existence. Firstly, that it is possible to know things without directly experiencing them and secondly, that it is necessary to examine experiences that are shared, in relation to the world in which they are shared. For the first proof I rely on the argument for *a priori* knowledge developed by Immanuel Kant In his Critique of Pure Reason. In his critique Kant argued conclusively that we can know things *a priori* and that all of our knowledge is not limited to our direct experience of reality. (Kant 1855: 29,30)

3.2.2 *A Priori* Knowledge and Knowing without Direct Experience

To know there is necessary truth in knowledge we can show that what we think exists is both necessary and universal. The following argument is illustrative of *a priori* knowledge. If we think of a room with 50 persons in it on the 4th floor of a building somewhere that we have never been then we immediately know a surprising number of things about that room without ever having experienced it. The room must be of a minimum size so that it contains all the people without their bodies overlapping, it must have at least a door and some means of access from the ground level. The floor will also be sufficiently resistant to support the mass of the people etc, so we can know it embodies certain principles that are necessary for it to be a room. These principles are related to the essence of a room and they apply to all concepts of rooms wherever they are located in time and space, therefore concepts of any room that we may cogitate have properties of necessity and universality. In order for there to be truth in *a priori* knowledge it must be possible to determine by reason that the state of affairs intended about that knowledge is both universal and necessary.

3.2.3 *A Priori* Knowledge and Abstract Concepts of Existence

This argument can be extended to abstract noumena, for example, the types of judgment inherent in decisions and actions. The conscious relationship that we have with objects in the world is referred to in phenomenology as 'intentionality' and means that every act of consciousness is consciousness of, or toward an object (Sokolowski 2000: 9). Decisions and deliberate actions must of necessity have resulted from judgments and are due to the intentionality of the observer and their experience of reality. Judgements do not occur spontaneously without intentionality. An observer must intend a state of affairs on which to exercise judgements in order to establish systems of belief. Experiencing the same phenomena, different observers can and frequently do intend quite different problem spaces and exercise different judgements. Therefore judgements cannot be considered to be properties of phenomena. However, the ‘judgement residues’ in relation to cogitation of particular phenomena will all have judgments of a particular category so that they are universal. For example, when a particular material property of a number of objects is considered the observer typically exercises judgements of measurement, value and discrimination. These categories of judgements will be exercised whenever a comparison of materials is made and so that providing the proposition and contexts are similar, judgements of measurement, value and discrimination (see Lipman's taxonomy, table 1) are necessary and universal. Therefore all judgements are necessary and universal truths of the observer's intentionality and interactions with the phenomenal world. This holds irrespective of whether a judgement is correct or not. In considering whether a material is suitable for a particular application requires that a judgement is made but does not require that the observer's intentionality constructs a true state of affairs, merely that they must have made a series of particular judgements in discriminating the properties of the material.

3.2.4 Phenomenology, Embodied Consciousness and Activity Led Learning

The phenomenology of Merleau-Ponty concludes that *a priori* knowledge can be known to any other individual consciousness. Merleau-Ponty criticised and extended considerably the work of Husserl particularly in regard to perception and embodied cognition. Merleau-Ponty's ontological and epistemological framework in the 'Phenomenology of Perception' is particularly germane to this study of judgement capacity in ALL. A central idea in ALL is learning (a change in consciousness) through activity. Merleau-Ponty posited that consciousness is invested in the physical body and activity and not just in super position to it and body consciousness cannot be separable from its environment (Romdenh-Romluc 2011 :3). Merleau-Ponty was only partly in agreement with Husserl's position on the Transcendental-Phenomenological Reduction (Merleau-Ponty 1945: preface xv). Whilst understanding and agreeing with its purpose he was not convinced it was possible to perform a complete and absolute reduction. He claimed it was only possible to suspend assumptions about the external world and that it was impossible to totally suspend belief in it. He thought that Husserl also came to realise the problem with this in his later work. For Merleau-Ponty, experience simply could not be considered without reference to the world and its objects.

3.2.5 Shared Reality, Experience and Subjectivity

Further, Merleau-Ponty provides another account of inter-subjectivity that I may rely on. He reasons that we observe others as embodied conscious individuals and not as objects so that we are aware that others can experience us in the same way that we experience them hence there is a symmetry in awareness and conscious existence (Romdenh-Romluc 2011: 153). Therefore where we share the same inseparable environment, there is symmetry in the awareness of experience and the construction of knowledge by other agents and the judgments that precede their decisions and actions are in the same categories as those made by ourselves. In considering the judgements that another agent may make given particular circumstances, we are also aware of the effects of those circumstances on ourselves and on the judgements we make. An account of experience by an agent is meaningful in as much as it conveys the agent's perception and understanding of that experience and since events are temporally and spatially unique they provide an absolute existential point of reference whereby the experience of agents may be usefully compared. To conclude, neither Husserl nor Merleau-Ponty rejected empiricism, however they considered it incomplete and unable to account for all of human experience. Phenomenology provides an epistemological position from which we can know that judgements exist and are known from their residues. In shared reality, experience has a kind of symmetry and knowing the environment in which mental states transact with reality is a fundamental step in understanding the experience of other agents. The theoretical framework of this research project is founded principally in the phenomenology of Merleau-Ponty and acknowledges that knowledge is not given but constructed by the perceiver from independent existence and the diversity in which reality is experienced. If we explain the phenomena we perceive we describe them and there is actually no distinct frontier between description and explanation.

3.2.6 Qualitative Research Method

Qualitative research methods were the preferred paradigm. They offer a range of theoretical stances and methods appropriate to the inquiry and although they are not strictly founded in any particular unifying theory or methodology (Gray 2009:166) they are appropriate in a phenomenological enquiry. Multiple Qualitative Methods were employed for several reasons. They are methods coherent with the theoretical framework and are particularly useful because they enable examination of the research subjects' experience from the perspective of those individuals to illuminate and identify specific ALL judgment phenomena. Further, the research questions and research subjects are not totally amenable to one discrete qualitative data collection method or methodology and while there is a degree of dichotomy between the methods they have common epistemological perspectives that offer this multiple qualitative method approach. Using multiple qualitative methods also permits methodological triangulation and the potential to combine data collection activities such as, learner reports, interviews and participant & non-participant observation, permitting me, to be immersed in the phenomena whilst attempting to avoid the imposition of assumptions on the phenomena. While phenomenology has some overlap with other qualitative approaches including ethnography, hermeneutics and symbolic interactionism (Gray 2009:17), phenomenological research was selected as the most appropriate methodology for the reasons stated above. Phenomenological methods are especially useful to examine the experiences and perceptions of individuals from their own perspectives, enabling understanding of subjective experience and providing insights into the research subject's motivations and actions (Lester 1999:1).

3.2.7 Grounded Theory

Other methodologies that were considered but were rejected, include grounded theory and symbolic interactionism. Grounded Theory is often used in sociological studies and was influenced by Glaser and Strauss (Gray 2009:183) who argued that in applying the method of Grounded Theory a hypothesis is not formulated, to do so would result in a theoretical model that is not grounded in any of the data. Instead data is collected and interpreted to see what emerges from within it. There is already major research in the public domain about human judgement and decisions in psychological studies on cognition and learning. It has been a most necessary step to carry out a literature review in order to know what current received wisdom is to be found on the topic. Inevitably this rules out grounded theory method as an option since the accumulation of knowledge in a literature review can lead to the formulation of preconception and hypothesis albeit even in an implicit way. Moreover my research questions indicate solutions that are essentially descriptive, grounded theory however is not a method for exposition or describing phenomena.

3.2.8 Symbolic Interactionism

Symbolic Interactionism is another sociological research tool. It assumes that a physical reality exists by the social definitions of individuals, and that individuals do not transact with reality directly, but rather with their social understanding of reality. It further assumes that since we cannot fully understand human subjective consciousness our coherent view of social order is an illusion dependent on human interaction. The method uses research tools such as participant observation of social interaction to understand how groups function and interact. The method is complex and more suited to understanding social order and social structures than the judgment of individuals or groups of individuals. Undeniably judgments are often made within the influence of social groups and are affected by the social adaption biases of representativeness, intention attribution and imitation behaviours. The way judgements are exercised in these environments can be seen in the four case studies, all of which involve team working. The focus of this thesis however is on the development of judgment capacity in a particular learning environment. My research aims to study the ways in which individuals interpret events, actions and abstract ideas and is centred on those phenomena. The focus of symbolic interactionism is essentially toward understanding social transaction and perceptions.

3.2.9 Summarising the Case for a Phenomenological Approach

The study of human judgement necessitates the description of a human cognitive process that cannot be experienced directly. A phenomenological ontology and epistemology have been established in detail in order to justify the selection of the qualitative methodology and method that was employed. The following issues were decisive in the adoption of a phenomenological approach

a) Judgements cannot be directly perceived, only the actions and decisions that result from them can be perceived directly by an observer.
b) It is possible however, to know things that are not directly experienced.
c) In shared reality, concepts are true if they are universal and necessary.
d) Given the same circumstances, the judgements that precede the actions of others are of the same categories as our own judgements.
e) Observing the experiences of the learner, their judgements in the context of a particular environment can be known from their actions and dialogues.

The research method and tools that were employed in this study were selected because they permit a detailed phenomenological approach. The tools permit the capture of the experience of the research subject without being obtrusive, requiring little or no additional effort on the part of the participants.

4. Research Method

4.1 Answering the Research Questions

Working from the current definition of ALL in Coventry University, the first research question is addressed in its entirety in the body of the literature review. The question asks, “Where does ALL as defined by Coventry University, fit within existing models of learning and the development of professional judgement capacity in learners?”

In summary, the literature review provided a comprehensive exposition of:

1. The role of judgement in professional practice
2. The nature of judgment and decision making in learning processes, human affairs and professional competence and performance
3. Potential approaches in ALL, from the contexts of experiential learning processes, problem solving and human cognitive architecture.
4. The influence of human cognitive evolution on judgement and the impact of cognitive bias.

Reading was taken from the texts of seminal works from authors in philosophy, education, professional development, psychology and human cognition. Relevant research papers in the same disciplines were also included.
The second research question, “How does current ALL practice fit in this framework?” requires that the current ALL praxis across the research area is understood in terms of its content, delivery and learning objectives. This knowledge is acquired from the delivery notes, and project specifications provided by the tutors. These documents contain the scope of the work that the learner needs to complete and the criteria that set expectations of the standards that the work should meet. Examining these in conjunction with non-participant and participant observations of delivery and project activity, an indication of the extent to which current ALL practice fits the framework can be determined.

The ALL environments in this body of research were various kinds of problem solving activity in aerospace engineering, production engineering, mechanical & automotive and manufacturing and civil engineering architecture and built environment. The third research question is the principal research question and is answered by the main body of research into judgement capacity. The data collected from each learner project was written into a case study of events in chronological order together with an analysis. Taking this approach enabled me to observe how judgements are exercised and re-exercised longitudinally as the problem solution develops. In total four case studies were conducted. From the completed case studies the learner experiences of making judgments can be understood within the contexts that they arise and how the construction of ALL experiences influence them.

4.1.1 Scope of Engineering Disciplines in this Research

The programme of research was undertaken with undergraduate learners in the Aerospace, Mechanical, Computing and Civil & Built Environment departments of Coventry University and apprentices on a Production Engineering course currently being conducted at a Precision Manufacturing Engineering Company in the North East of England. These areas I specifically selected for the research field. They were chosen because they offered a range of ALL environments across those engineering disciplines with the possibility of a comparing ALL interventions between undergraduate programme and dedicated work place provision. The interventions are amenable to participant and non-participant observation that is unobtrusive. Within the current definition of ALL at Coventry University, each of these disciplines uses ALL as a delivery paradigm. Ethical approval to collect data on human subjects was obtained from the Ethics Approvals Board at the university.

4.1.2 Apprenticeship Production Engineering Programme Background

The apprenticeship programme with the North East employer proceeds by virtue of a contractual agreement between the employer, an intermediary training agency and myself. The programme began in October 2012 and is in its third year of delivery. Nineteen apprentices were recruited to the programme in 2012, eighteen started the programme in October 2013 and a further twenty one from October 2014. Twelve of the original cohort progressed to the intermediate stage and 4 went on to the advanced level. Of the second cohort of eighteen, 8 progressed to the intermediate stage. The programme's strategic aim is for continuing professional development in production engineering skills. It is compelled by business case rather than any view of necessity to train for competence or regulatory compliance. The intermediate apprentices are the subject of this research.

4.1.3 Undergraduate Programme Background

The undergraduate student participants were recruited from first and final year undergraduate learners from the department of Aerospace, second year students from the department of Mechanical, Automotive and Manufacturing Engineering, and third year students from the Department of Civil Engineering, Architecture and Building. These departments had all implemented ALL interventions and ALL activities appropriate to this research were identified in consultation with the tutors from the aforementioned departments.

4.2. Risks to the research

4.2.1 Ethics, Participant Confidentiality and Data Security

The research methods and data collection tools conform to British Educational Research Association (BERA) guidelines 2011 and were also approved by the ethics approval board at the Coventry University before data collection took place. The ethics approval forms are presented in appendix 21.

a) In accordance with BERA articles 8 & 9, research was undertaken with all due respect to the participants and individual participants were all treated fairly. Participants were recruited opportunistically across the engineering faculty departments or the apprenticeship programme, there was no rationale or attempt to restrict or coerce participation from any particular department or by ethnicity, gender, sexual orientation, race, creed, religion.
b) In accordance with BERA article 10, the purposes of the research were disclosed and explained to the participants and provided in writing before they indicated their commitment. The purposes were open and data collection was unobtrusive and performed while learners were engaged in normal pedagogic activities.
c) In accordance with BERA article 14, there was no covert observation, subterfuge or deception needed in the data collection and no deception was required to secure participation.

d) In accordance with BERA article 10, every participant was a volunteer and gave their informed consent in writing on a dedicated proforma (appendix 4). The consent document was provided together with a participant information sheet (appendices 7 & 8). The participants were informed that they could withdraw at any time without providing a reason. In the few cases this occurred the withdrawing participant was not coerced to reconsider. Individual data was discarded in the event that a participant withdrew unless their anonymised data had been aggregated into a general pool of data and could not be readily re-identified and extracted. The participants were informed of this possibility. In the cases of the apprentices they have a contractual obligation to their employer with respect to their programme of study and as their tutor I was contractually obligated to their employer to keep such records as required for the discharge of that duty. In the event that an apprentice withdrew I could remove their data from study but was still obliged to provide data on their performances for their employer. Throughout the duration of the study there were no apprentice withdrawals.

e) In accordance with BERA article 22, no incentives were offered to any of the participants

f) In accordance with BERA articles 23 & 24, there is no predictable detriment or advantage to any of the participants or participant groups. The learner activities being researched were the normal educational activities of the participants and were not specifically designed to place them under any unusual duress or psychological stress for the purposes of measuring those reactions (BERA article 20).

g) In accordance with BERA article 25, collected data used for this research was anonymised to preserve the participant's rights to privacy and confidentiality. Individual's were assigned to teams for the purposes of project work and those teams were assigned names, letters or numbers for purposes of reference.

h) Observation record transcripts and video recordings are kept in a locked and secure repository remote from the data collection sites the location of which is known only to the researcher. Storing data as hard copies or CDROM video files off a computer system eliminates any risk to the integrity of the data due to system failure, file corruption, system virus or cyber penetration. It further requires that records have to be re-transcribed from the original. The risk to the project is that there being no duplicates, loss of data would have been catastrophic.

4.2.2. Impact of Apprentice Programme Delivery on Data Collection

The programme is well established and it was not anticipated that there would be any premature determination of the programme during the data collection period. All the apprentices recruited by the employer have to have minimum GCSE grade C in mathematics, English language and a science subject and pass an aptitude test at recruitment. The ages of the apprentices are from 18 to 22 years and the ability and conation of the apprentices is over a wide range. While the learner diversity lends itself to an ALL community of enquiry, approximately 50% of the apprentice learners expressed a preference for tutor led learning and find the ALL environment challenging, necessitating greater than anticipated levels of tutor support and intervention. The necessity to facilitate close learner support detracted from opportunities to observe and record the learning process.

4.2.3. Impact of Undergraduate Programme Delivery on Data Collection

Student cohorts in each of the university engineering departments are quite large and it was not anticipated that there would be any difficulties in recruiting research subjects. Timetabling clashes arising between some groups of research subjects impacted upon data collection opportunities. Often choices had to be made as to which group or groups could be observed at any one time and in consequence, data collection was often opportunistic. Many group meetings and activities had to be observed out of their normal tutorial time and data collection opportunities relied heavily on being able to establish a rapport with a learner who would inform me when and where their next meetings took place. Inevitably learners in different groups within the same discipline have similar timetables and this resulted in further clashes in observation opportunities. A small number of undergraduate students withdrew from the data collection programme voluntarily and some dropped out incidentally due to being withdrawn from their course of study.

4.3. Research Tools and Data Collection Methods

4.3.1. Trialling Research Tools and Data Collection

For the purpose of trialling the methods and documentation for data collection, a preliminary study was carried out on the first cohort of the apprentice production engineering programme in 2012. These included participant observation, log books, document analysis, and semi-structured interviews. The learners were studying BTEC level 2 and 3 manufacturing and production engineering as part of an apprenticeship to become CNC machine operators or technicians. All had acquired various levels of competence in performing engineering operations and some facility with the operational use of CNC machinery. The preliminary study was carried out between October 2012 and June 2013. I observed and recorded the activity of the teams, and each team kept a log book detailing the activities from their perspective. From these records the judgements made by the groups and individuals were induced from the decisions actions and events that were recorded. The study demonstrated the potential of multiple method qualitative approach in the analysis of judgement in ALL environments. It also usefully highlighted particular areas for further development in documentation design and improvement of administrative procedure.

4.3.2 Rationale for the selection of the Case Studies

The rationale for the selection of the ALL environments for research is set out herewith. The programme of research was undertaken with undergraduate learners in the Aerospace, Mechanical, Computing and Civil Engineering & Built Environment departments of Coventry University and 3rd year apprentices on a production engineering learning and development programme at a precision manufacturing engineering company in the north east of England. Four case studies were selected, the characteristics of each study is summarised in Table 2.

Selection was primarily and principally determined by the intention to study an eclectic range of engineering ALL interventions. It could not be assumed that all ALL interventions would have entirely similar modes of delivery or assessment and studying a broad range of provision might indicate whether variations in the exertion of judgement was due to styles of delivery or local effects. A longitudinal study of one particular engineering discipline would have provided a useful study of how a particular group of learners developed throughout their studies however, the time scale for data collection and the overall project did not permit this approach. Moreover a criticism of phenomenological studies is a tendency to focus on small focus groups with the subsequent claim that extrapolation or generalisation of conclusions from any findings to other disciplines and situations is difficult to substantiate (Gray 2009:28). An eclectic approach across disciplines that included apprentices as well as undergraduate learners provides greater confidence that the findings apply more generally. Case studies are qualitative methods that are useful for exploring themes or propositions by focussing on groups and can highlight issues about organisational behaviour, or the design, implementation and effects of projects (Gray2009:246,247). He goes on to explain that the case study approach is particularly useful in trying to discover the relationships between phenomena and context.

Some selection pressures were opportunistic. A preliminary survey of provision through discussions with tutors across the faculty indentified a number of potential ALL projects. When the timetabling of these programmes was examined the final choice was made from those that presented both a good range of diverse activities but were also accessible in terms of environment and timetabling. Programmes where activities were located in large lecture theatre settings or those that presented time tabling clashes were inhibiting of appropriate or consistent data collection opportunities and consequently the ALL interventions selected for study were amenable to unobtrusive participant and non-participant observation of learners working in self directed small teams.

The ALL scenarios differ in the kind of learning opportunities that are being delivered. Case study 1, The Aerospace Crash Investigation project explores causality, and reasoning from evidence to reconstruct an event. Case study 2, The apprentices' Design and Construction of a CNC Work-holding System project is a design, construct and implementation project to solve a real work place problem. Case study 3, the Mechanical Design & Sustainability projects have a focus on product design that exercises methods and strategies in mechanical design and manufacturing
and Case study 4, the Built Environment Design Integrated Project is a complex interdisciplinary project to redesign a building.

Table 2: Comparative Summary of Case Studies

	Case Study Title	Description	QCF Level*	Discipline	Assessment	Project duration	No. students observed
Case Study 1:	'Crash Investigation' 1st year Aerospace module 103SE.	Investigation of the events and circumstances of an airplane crash involving the analysis of diverse evidence to establish the cause.	4	Aerospace engineering	Report and 2 presentations	9 weeks	36
Case Study 2:	Design and Construction of CNC Work-holding System	Investigation of a real work place production problem and the design and implementation of a solution to the problem.	4	Production engineering	Logbook and 2 presentations	33 weeks	12
Case Study 3:	Mechanical Design & Sustainability Assignments 1 & 2	2 mechanical designs projects, 1st a linkage motion transfer project and the 2nd the product design of an engine hoist for a specified market.	5	Manufacturing & Automotive	Report	13 weeks each	12
Case Study 4:	Built Environment Design Integrated Project	An interdisciplinary project on the refurbishment for improvement and design of an extension to an existing faculty building.	6	Civil Engineering & Building	Report and presentation	24 weeks	23

The QCF level for apprentices is at level 4. Although a BTEC apprenticeship is normally at QCF level 3, the apprentices in this study were enrolled on an HNC programme and this is the level of the ALL intervention in case study 2. In addition to design conception and draughting a solution to a real life production problem they also have to machine and fabricate their design to high degrees of precision. Their project also includes project and financial planning and the presentation of their finished proposal and working model to senior executives in their companies. For this reason the programme presents challenges that in some instances are comparable or may exceed the demands of undergraduate work at QCF level 4.

4.3.3 Research Tools

The following research tools were approved by the ethical approval board at Coventry University and were used for the purposes of collecting data on the learner's experiences. Table. 2 refers.

Table 2. Data Collection tools and methods.

Data collection tools and method	Research Group
Manually recorded researcher-participant observation	Apprentices
Manually recorded researcher-nonparticipant observation	Undergraduate learners
Reflective Precis	Undergraduate learners
Manually recorded, selected semi structured interview	Apprentices & Undergraduate learners
Selected video recording	Undergraduate learners
Learner recorded Log books	Apprentices

4.3.4 Manually Recorded Observation

A phenomenological stance is taken by the observer so that lived experience is not given objectively but describes how individuals and groups of individuals construct experience. Records of observations enable the capture of individual actions and dialogues within the interaction of the group. From the observation records and analysis of the 'judgement residues' it is possible to know the individual learner's judgments and how interaction with the learning environment and group affects the exercise of judgement. Manual records are a punctuated series of descriptions that reveal salient features of the learners' experiences as observed by the researcher. Manually recorded observation was used with both under-graduate and apprentice groups. Manual recording has the advantage that 'noise' can be ignored and events of particular interest can be captured. Its disadvantage is the risk that something may evade notice or that events proceed at a pace that cannot be easily written down. The technique is largely unobtrusive and all learners appeared to relax and display little awareness that their actions were being noted.

In the case of the undergraduates I was a non-participant and opportunistic observations could be made without interruption. The undergraduates were generally more reticent and unless they had convened a meeting specifically to discuss some issues were inclined to work quietly, sometimes independently or in pairs and some, even in different parts of the room. Prompting them briefly with a question like, "What stage are you at now?" produced useful cascades of action and dialogue that would have otherwise not presented themselves. Some participants were absent and when observations take place in one session a week a participant may not be observed for several weeks. It was also more difficult to get participant undergraduates to communicate their whereabouts if they had convened extra tutorial meetings. In comparison the apprentices are rarely absent and contact is at a high level. In tutorial team activities discussion is almost constant and action was a noticeable feature that required little elicitation. Observation however was often interrupted by a learner asking a question and the necessity to stop observing and recording activities and temporarily assume the role of tutor.

4.3.5 Reflective Precis

The reflective precis consisted of five questions directed at eliciting a reflective summary of the decisions made by a team during a particular activity. This method was used sporadically and opportunistically with undergraduate learners only, as a way of capturing the way individual team members exercise judgements of hypotheticality, counterfactuality, instrumentality and value. See 2.5.2 Table 1. Asking undergraduate learners to complete a regular logbook was thought to be too difficult to control and potentially placed a burden on participants that may have reduced participation rates. The following questions were used for the reflective precis. (appendix 5)

- What decisions were made by you or your group in today's activity?
- Who made the most important decision and why do you think it was important?
- Which of the decisions made by the group did you disagree with and why?
- What alternative decisions were possible? Why were they not presented/accepted?
- What effective/appropriate solutions/actions will result from the decision?

In practice it was found that the reflective precis was difficult to implement. Many lectures terminated suddenly and in time for students to move to other activities leaving little time for learners to complete the precis appropriately and many responses were cursory or omitted altogether. It was also found to be impractical to find some convenient point in the tutorials to be able to clarify any questions that arose. The precis forms were only used with aerospace first year students and second year mechanical, automotive and manufacturing groups then the idea was discarded.

4.3.6.Logbook

The apprentices completed team logbooks as part of their project assessment. Marks were awarded according to how well the logbook is kept and the audit trail generated was used as raw data for the apprentice case study. The use of logbooks is a good phenomenological tool for capturing the residues of mediating and culminating judgments from the learners' perspective. There are several advantages and disadvantages in the application of this research tool. Primarily the logbook is entirely constructed according to the intentionality of the writer, there are only basic prompts and each entry depends upon the writer re-activating memories of particular events. Logbooks provide a longitudinal view of the way judgements determine the events and disjunctures that impact upon the way in which later judgements are exercised. The data contains varying degrees of detail of the actions and decisions of the apprentices together with some technical detail of their project work.

Logbook entries can vary significantly, those presenting good detail are a rich source of the progression of thinking and the judgments made by the learners. Some entries can be quite cursory and reveal little. In making a logbook entry, the learners provide a brief outline of planned work at the start of each session. This provides information about their intentionality of the problem space. At the end of each session they should complete the reflective sections in which they record in detail work that was actually done and account for any alterations to plan and any alternatives they had considered. It is important that this latter section is completed as soon as possible while events can be readily recalled. Where significant delays occur, the individual completing the entry recalls those events and issues that most readily form a coherent narrative in hindsight.

A disadvantage of the logbook as a research data collection tool is that learners have to be encouraged to use them and given examples of how to use them. The apprentices sometimes left pages or part pages blank even though they were aware that it contributed to a reduction in their final marks. Logbook detail tends to improve as time goes on and the learners adapt to the feedback that they receive. The logbook was not considered appropriate for undergraduate learners, in many cases it is not a requirement of their modules and would have placed a burden on the participants, also there is difficulty in maintaining regular contact with the undergraduate participants and in monitoring and controlling their use of the logbook. Appendix 6 shows an example logbook page.

4.3.7. Semi-structured Interview

Some learners were selected to voluntarily participate in a semi-structured interview typically lasting 30 - 40 minutes. Participant selection was broadly opportunistic however some selections were guided by specific interests that had been noted during observation or whether it had emerged in the course of being observed that particular issues needed to be explored further. During the interviews I occasionally prompted for further detail to draw the learners to focus briefly on a particular aspect of their experience; however, the interviewees dialogues were allowed to flow from the learners' own memories of their experiences. Interviews were all carried out soon after the end of the project and the interviewee is recalling experiences that are either very recent or within the last few weeks.

In re-collective and reflective practise learners often make justifications for actions and beliefs that permit potential access to a range of complex culminating judgments of counterfactuality and instrumentality. I expected the interview transcripts to elucidate learner experiences in greater detail than could be observed. The interviews however revealed other characteristics about recollection, memory and narratives. While hindsight has some impact on the recollection of experience, the experiencing self and remembering self are not equivalent and the narratives produced by the act of recalling and reactivating experiences focussed much more on social issues than the technical demands.

4.3.8 Video Recording

Video recordings were made of some groups making presentations of their project work. The presentations were of approximately ten to fifteen minutes in duration, some displaying several solutions to a particular problem. Video usefully captures aspects of intentionality of the learners particularly in the way they interpreted the requirements of the project criteria. Body language and presence are apparent giving useful indications of the level of confidence they display in their thinking. All research participants signed an informed consent document (appendix 4 refers). The consent document was provided together with a participant information sheet (appendices 7 & 8). Informed consent documentation permitted the potential participant to opt for all aspects of the research or opt out of particular aspects by selecting appropriate boxes. For example a learner could on the same form consent to being observed but declare that they did not wish to be on a video or audio recording.

4.4. Data Extraction and Analysis

4.4.1 Introduction

The raw data generated by the research method consists of essentially 2 categories. The project specifications provided to the learners at the beginning of their ALL project are used to understand the scope of the problem space provided to the learner. Secondly, the descriptive passages taken by myself as an observer and auto-descriptive notes provided by the learners of their own decisions and activities provide an audit trail of the learner's interactions with that problem space. This information on presentation does not readily reveal the problem space nor any of the judgements made by the participants from merely reading the descriptions. The information obtained has to be read for meaning and context and the problem space and judgements inferred from that information. This chapter deals with that process. Firstly from discussion on professional judgement in a method of understanding the problem space is discussed and was developed from discussions on professional judgement and development in sub sections 2.1.1 to 2.1.5 and problem solving in subsections 2.4.2 to 2.4.6 of the literature review. 2 examples of learners making judgements are given in sub sections 4.4.5 and 4.4.6 together with a discussion of the approach to analysis and the inference of judgement.

4.4.2 Engineering Problem Space, the Technical and Socio-technical Demands in Problem Solving

One aspect of the learner experience in project based learning is their intentionality of the problem space as it is given. The project specification may suggest a problem space dominated by the technical considerations of mathematics, materials, regulatory issues and other rule based and issues or it may have socio-technical demands that value laden and difficult to quantify, inviting consideration of the human condition and similar holistic issues. The term socio-technical is used in this research to denote the social intentionality of engineering students or engineering professionals as a group distinct from the general lay population. Because these individuals have technical knowledge or expertise any problem space they intend will be affected by their appreciation of technical issues. This contrasts with the lay 'person on the street' who may have no technical knowledge and who will intend a problem space that is confabulated or socially deterministic.

To try to qualify this aspect the project specifications and marking criteria were obtained from the course tutors and the descriptions and narratives were examined to determine to what extent the projects invited technical intentionality or socio-technical intentionality. This categorisation is largely subjective but there is a distinction between these two aspects and the process is by no means entirely bereft of any objectivity. For example a design specification asking for a structural analysis is of the technical domain whereas if the specification were to consider some ergonomic or utility or the impact on an intended user then it also has definite socio-technical domain. Subjectively, the relative proportions in terms of the cognitive load or complexity of these attributes can be plotted on the diagram below (Fig.1.)

4.4.3 Problem Space Domains

Fig.1. below was first published at the SEFI Annual Conference 2014 (Igarashi et al 2014: 4) It shows a problem space map for engineering problems plotting the socio-technical domain against the technical domain.

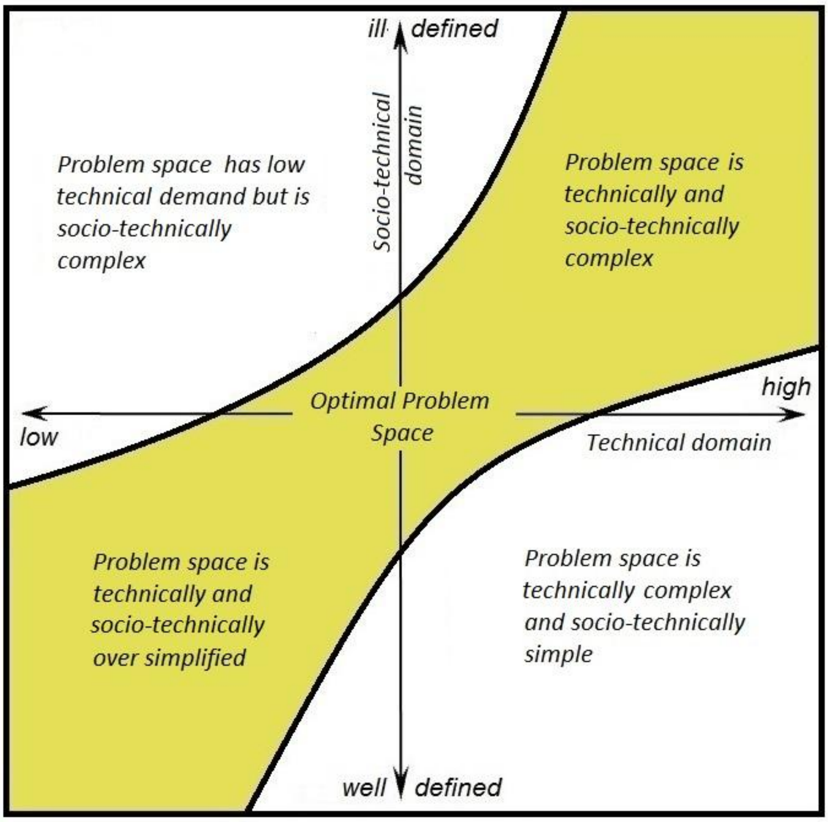

Fig.1 Engineering Problem Space

It was hypothesised that any engineering project or problem experience in a learning environment or professional practice would lie somewhere in these 2 domains and that experiences most resembling those that exercise judgement in real world practice would occupy a problem space tending toward complexity in both domains. Where both domains are oversimplified the learner may not be sufficiently taxed or presented with anything unusual on which to make any judgements. At the other extreme where both domains are complicated and tending to what are referred to as 'wicked' problems where there are no absolutely correct solutions (Rittel & Webber 1973:160), the learner may be overwhelmed by the complexity of the problem space and in attempting to resolve it, acquire erroneous patterns in making judgements of causality and factuality. The learner may then have to seek support to be provided with a partial solution rather than think it through themselves. For the purposes of ALL, an optimal problem space may be thought to be one in which the demands on the learner are sufficient for them to exercise reasoning.

Problem spaces that are technically dominant with negligible socio-technical issues still provide useful learning experiences. Problems of this nature occur in industrial settings where work is focussed on one part of a much larger problem. Judgements in this domain can be rational and supported by recourse to data and mathematical models without the need to make adjustments to accommodate socio-technical pressures. A problem space dominated by socio-technical issues with little technical input may occur in specific circumstances, for example if the social utility of a particular design or development was the main consideration in a project specification. Judgements exercised in this area of the problem space could be value laden and solutions may appeal to emotive solutions as opposed to any particular rationale.

4.4.4 Induction of Judgment from Data

An important attribute of observation records, interview records, videos and logbooks is they record what is seen by the observer or what is reported by the learner and are therefore direct phenomenological representations of experience. Because they are records of judgment residues and not of actual judgments they have to be read and analysed for meaning and context. Lipman’s taxonomy of judgment gives a useful starting point however a unique feature of this research is the identification of additional judgement categories for use with that taxonomic framework in conjunction with the heuristic and bounded rational model of judgment proposed by Khaneman. Lipman's taxonomy places judgment into different categories that define judgment in a simple way depending on a particular action being the result of a particular judgment. One can see how this works in the following 2 examples.

4.4.5 Example of Undergraduate Learner Judgement

A decision to use a particular material in the design of an artefact was expressed thus:-

> *"Our material of choice for the improved design was titanium because it is corrosion resistant, tougher and stronger and therefore we could use a lighter section and the design would be lighter than the original. Comparing costs it will also be cheaper because we are using less material."*

Reading for meaning, the descriptive transcript is encoded according to Lipman's taxonomy. The above quotation reveals the following judgments were made, 'membership' or 'composition' - titanium is part of or belongs to a class of metals with certain properties; 'relevance' - titanium is a material used in aerospace applications or more broadly this argument bears a relation to this particular problem space; 'discrimination' - this metal has properties that differ from other materials (within the context); 'reference' - (comparison) this metal was selected because it surpasses the properties of others we could have chosen; 'factual' - This evidence was sufficient for us to make our selection.

Khaneman (2011: 20 & 81) on the other hand examines judgment as a function of two distinct cognitive mechanisms that he refers to as system 1 which is fast or heuristic thinking and system 2 which is slow or rational thinking. Fast thinking is dominant and generally over rules system 2. Initial belief in a proposition is down to system 1 when the individual intends a heuristic best fit interpretation of a situation. If system 2 fails to overrule system 1 then even an absurd proposition will be believed. System 2 requires considerable cognitive effort and time to complete a task while system 1 assesses situations quickly and builds plausible and coherent narratives of experience.

Applying Khaneman's hypothesis to the titanium selection scenario and the context in which it was made we can now see it adds another dimension to the breadth of the taxonomy and real world judgment is actually richer and more complex than Lipman's basic model. The selection of titanium was based broadly on its properties and the received wisdom of its use in typical aerospace applications. The teams were under pressure of meeting a deadline and marks for this particular project were a low 10% for the module. This issue alone will drive the learners to make heuristic judgements rather than invest any effort. No evidence by way of referral to data or calculation was offered and the considerable difficulty and cost of machining titanium was not considered in the problem space. The judgement to use titanium was an availability heuristic, constructing the best possible narrative from currently active ideas (Khaneman 2011:85).

Although Lipman’s taxonomy can be applied easily in some circumstances, there are instances that are more complex. Inferring judgements of composition about which parts belong to a mechanism can be easy, detecting that a judgement of composition has been exercised about what is relevant to an ill-defined problem space is much more difficult, and from Khaneman's work judgements can be either rational or heuristic. For example a judgement of factuality based on a statistical analysis of distribution data on the reliability of a car make is rational. A heuristic judgement of factuality about reliability will be prone to bias due to availability and representativeness heuristics. We can see from this example that although these are both judgements of factuality they are in fact qualitatively quite distinct judgements and each will affect the way the observer intends their thoughts and actions with their world view in very different ways. Lipman's taxonomy is actually not straightforward in all applications. Judgements are more complex, much richer than was anticipated at the outset of the research and analysis requires careful consideration of the learner's interaction with the problem space.

Heuristic judgement is fast and much better than any random selection by sheer chance but by failing to do calculations on materials and manufacturing data it clearly runs considerable risk of developing an unworkable or unprofitable design. Data and calculations could have provided basis for sound professional judgment but calculation is a system 2 cognition and they were unwilling to expend the effort. Where there are several ways to solve a problem, individuals will take the least demanding course of action, driven by economy of effort. Effort is costly and has to be offset by the benefits (Khaneman 2011:35).

4.4.6 Example of Apprentice Learner Judgement

The following statement is taken from a presentation made by a group of apprentices when attempting to justify an issue.

> *"We were unable to complete the machining on the clamping mechanism because the CNC lathe was out of action"*

Again from Lipman's taxonomy the potential judgements are 'discrimination' - CNC machining was the only way to complete the action; 'relevance'- the considered argument is relevant to this particular problem space; 'instrumentality' - means end adjustment i.e. justification of inaction by implying they had no alternative course of action. Khaneman may express this as a false dilemma or bifurcation fallacy. They have presented a self justification by implying there is only one choice, one solution that was denied them. The implication being they could have finished with access to a particular machine. This argument rejects the possibilities of other viable methods that would have enabled them to complete their work or even acknowledgement that other impediments may have prevented them. The machine was only unavailable for 6 hours.

4.4.7 Analytical Procedure

In the two examples above the procedure for analysis and inference of judgement firstly requires that the parts of speech related to existence, action, thought and decision (verbs) are recognised in the statements. All of these constitute the main residues of judgements and from them we can assert that they were preceded by particular categories of judgements. Secondly in connection with the aforementioned, any parts of speech such as adverbs and adjectives must also be noted because they qualify and shade actions and are common in all the types of judgements of discrimination. The inference of judgement then involves the analyst intending the state of affairs that led to the action, viz literally placing themselves in the position of the participant and cogitate the judgements that could have constructed the actions. This is easier in some instances than others. The judgements are then examined to determine whether they are either system 1 and heuristic, or system 2 and rational. The statements are examined to see if there is evidence of system 2 thinking, if this is absent then the indication is that in all probability a heuristic judgement was made. The following statements illustrate the method;

1. "The most likely cause of failures of this type of hydraulic pump is probably incorrect pre-loading of the bearings."
2. "I know several cases where hydraulic pumps of pumps of this type failed due to incorrect pre-loading of the bearings, it'll be the most likely cause."
3. "The data distribution of failure modes for this pump show that the main cause of failures was due to incorrect pre-loading of the bearings."
4. "The cause of failures of this type of hydraulic pump is incorrect pre-loading of the bearings."

Statement 1 is a heuristic judgement of relevance and causality, so is statement 2. The person making these judgements is re-activating memories that are constructed into a narrative that makes sense to them. The availability heuristic will ensure that recent memories appear more important and more likely and disregarding records or data distribution that might challenge any misconceptions is a good way to sustain misconceived systems of belief (Khaneman et al 1982). On the other hand statement 3 is a judgement based on statistical evidence that has had to be examined and interpreted to make sense of it. This involves cognitive effort that requires system 2, rational thinking because system 1 heuristic thinking is not evolved to cope with numerical calculations. Statement 4 as it stands is indeterminable, in the absence of further information about the circumstances in which the judgement was made. If it is a culminating judgement that evolved from mediating heuristic or rational arguments then we can say something about it.

4.4.8 Presentation of Case Studies

The research data and analyses are presented as 4 discrete case studies detailing each environment uniquely as it was presented. A decision was made to interleave the analyses with the recorded data. In so doing the phenomenal field was preserved so that judgements could be seen to be directly inferred from the data and any intentionality that could affect selection of data to support arguments and assumptions about the problem spaces was suspended.

Extracts of the learners' actions and dialogues are presented chronologically in the order that they were given during data collection. The case studies follow a similar structure where the observations of the learners' experiences and interactions on a particular date are given interleaved with comments about the judgements made followed by an analysis of the judgements they have exercised.

The observations were opportunistic over a period of time and presenting the findings in chronological order is in keeping with phenomenological methodology. Describing the phenomena as they are given preserves the phenomena and there is no suggestion that the experiences as they were given have been subject to deliberate selection. This approach also enables a longitudinal view of the judgements that were exercised over the duration of the project. Adopting this structure the way successive judgements develop through the learners' experiences can be seen.
To make distinction between the various parts of the case study, the main body text addressing the reader and containing any preamble and explanations is given in normal 11 point Arial font. Learner dialogue and comments are indented within quotation marks.

An outline of each ALL project is presented first followed by the phenomenology of the learners' experience containing the data relating to the learner experience in the order of; observations of team activity then reflective precis and semi structured interviews. Analysis of judgements is interleaved with the data and followed by a section providing a discussion and analysis in overview. This section also highlights particular issues germane to each case study and may therefore contain subsections only relevant to the case study in question.

In Case Study 2 all 4 groups where observed on each occasion. For this reason and in order to better structure the presentation and correlation between log book entries and observation events, the study is written so that the experiences are given chronologically and each group is considered in the same time frame.

5 Case Study 1: 'Crash Investigation' 1st year Aerospace module 103SE.

5.1 Introduction

The 1st year Aerospace Crash Investigation project specification shown below is provided by the aerospace tutorial team at Coventry University. It was the first of 2 ALL projects in the 1st year of the BEng degree in Aerospace Technology in 2013. The projects aimed to engage and enthuse students and introduce them to the technologies of Aerospace Engineering. Learners have access to diverse information sources related to aircraft design, construction and maintenance, wind tunnels and flight simulators. There were 116 in the cohort of 2013 of which 10 were female. The groups were selected by the tutor and were typically 6 in size. There were no mature students in the cohort which suggests that few if any had any previous industrial experience. The full project specification and marking scheme together with tutor's project documentation is given in appendix 9. Larger records of the observations and descriptions of learner activity for this case study are given in appendix 14.

5.1.1 Project Specification Outline

Not all of the project information is provided in the specification. At an initial briefing the students are given the circumstances of the crash including the aircraft type, destination, departure airfield, take off time, payload/cargo, flight safety record/history, fatalities, and that the crew's families have not been informed but are being informed now. Using this information their first task is to prepare a video of a newsflash after which they conduct an investigation of the crash and produce a report. In the first week the following information is given to the students; a meteorological report, several eye witness accounts, technical Log and Air Traffic Control Report/statement including Bird Unit report and any terrorist intelligence. In week 3 they are given the Aircraft Trade Diary and in week 5 the Cockpit Voice Recorder and Accident Data Recorder transcripts. The following information is available but only on request; Airworthiness Directive, Air Proximity Report, Interview with other aircraft Pilot, Extra TLP Supp servicing sheets, Crew Details.

Among possible conclusions the one most appropriate considering all the evidence in the scenario is that the aircraft is an older series 200 A320 and the whole wing on one side failed due to fatigue and broke free due to the stress imposed by a severe evasive manoeuvre. The evasion occurs due to the sudden incursion of another aircraft into the A320's flight path. This is possibly due to human error.

5.1.2 The Scope for Judgement in the Project Specification

With the information given in the project specification and subsequent tutorials, the students have to develop and present their research, findings and crash cause hypothesis. Specific objectives, or learning outcomes are not given enabling the activity to lead the learning process, inviting the students to form their own bounded rationality of the problem and develop a solution. Periodically the students receive additional information from the tutorial team and they may request additional information that they consider useful in their deliberations. Through discussion, examination of the evidence and further research the problem space is refined by a succession of judgments until they are in a position to form a hypothesis about the cause of the air crash. The specification exercises the intentionality of the students inviting them to exercise judgment in a number of instances. As they immerse themselves in the role of the AAIB in the activities of a newsflash, the investigation and the presentation of the findings, they will have to judge the relevance of diverse information sources and the fitness of any information for inclusion in their presentations. They also judge the relevance and appropriateness of information to the problem space including the absence of necessary information. They could make judgements about the necessity and appropriateness and efficacy of software tools and the extent of any research they carry out. The students will have to make a whole series of judgements about the rational progression of their arguments as the learning experience flows from one disjuncture to another. Finally working in a team especially a cross cultural one, involves judgments about agency, skills and intention attribution.

5.2 Phenomenology of the Learners' Experience

The students were observed both individually and working as groups over the period from 1st October to 3rd December 2013. Observations of activity mainly took place on Tuesday morning between 09:00 and 11:00 with additional observations with project teams by prior agreement. I made opportunistic observations on 25 occasions of the activities of 6 groups. Twelve of the observed students gave, on request, a reflective precis of their views of the group's work. Three semi-structured interviews were recorded with selected volunteers. The construction of disjuncture in this problem space arises from competing propositional attitudes. The aircraft makes a sudden evasive manoeuvre, there is a loss of mass, a fuel leak, contradictory eyewitness statements. They also considered, engine failures, cargo shifting, bird strikes, pilot error. The loss of mass is relevant but the learners have difficulty accounting for it. The learners attached importance to the salience of the fuel leak information. Solving that disjuncture holds the key to the problem.

5.2.1 Participant Group 1

1st Observation of Group 1 on 15/10/2013;

The learners begin by focussing on the flight log information. This indicates an initial heuristic judgment of relevance. This heuristic is a type of bounded rationality to reducing potential problem space. If the hunch is correct it would also produce a causal hypothesis in a short time. The log search indicates that a range of judgments were being made i.e. identity, membership, difference and composition, culminating with judgments of relevance and hypotheticality. The proposition to consider events with higher frequencies is potentially a form of the logical fallacy of representativeness.

2nd Observation of Group 1 and student reflective precis comments on 21/10/2013;

This is the second tutorial activity, students have prepared and are presenting a video of a news flash about the air crash. From experience of disaster newsreel videos, the students would recognise segments of any news flash as a part of a manifold of phenomena related to a whole newsflash. This potentially presents the problem space as a familiar object that should contain similar phenomena. The heuristic of bounded rationality that can be performed quickly and with certainty since they can readily think of the kinds of things that should be included and dismiss those that are extraneous. The judgements indicated in deciding the presentation content therefore are similarity, membership/composition, and culminating judgments of relevance, appropriateness and factuality. There is no evidence to support a view that skill assessment (appropriateness) or intention attribution forms decisions on who presents the news flash. It appears to be voluntary. In the three reflective precis, two students disagreed with team decisions indicating heuristic judgements of appropriateness and factuality. There was disagreement on procedure and perception of disorganisation that arise from judgments of practicality and difference. The proposition to split into smaller groups is a counterfactual judgment mediated by the instrumental judgement that it was over ruled by the group

3rd Observation of Group 1 on 05/11/2013;

The group activity is still directed toward problem space development by researching information on PCs. The students are now in possession of all the information that is given by the project specification and tutorial support. The learners exercised judgements of hypotheticality, relevance and causality They think there is relationship between 3 factual events and the later events are consequences of the earlier ones. In this heuristic judgement there is a potential 'pro hoc ergo propter hoc' fallacy that arises from a judgment of factuality, viz they have judged the sequence of these facts to be coherent and therefore likely to constitute sufficient evidence.

4th Observation of Group 1 on 07/11/2013;

In the early stages they begin by re-iterating their earlier discussion of the 5th on the evasive manoeuvre and fuel leak idea. Their problem space has become populated with a lot of data from the flight recorder and other reports that form propositions on which they exercise a range of more rational judgements, including measurement, value, relevance and composition. There is still a degree of uncertainty about the data and whether it provides sufficient evidence for the conclusion that is emerging and ultimately there are culminating judgments of factuality, counter-factuality and causality. Particularly salient is the dramatic decrease in mass and whether a fuel leak is sufficient evidence and therefore potentially causal.

The discussion later turns to the handling and attitude of the airplane and returns to the fuel leak argument. The off topic discussion indicates the onset of ego depletion among the participants. Although they are still making judgments of relevance and factuality the depletion results in increasing difficulty to exercise judgments on rational evidence and the emergence of heuristic judgements that require less cognitive effort. “Looks like a definite..........” “It’s more likely to...........” “Pretty obvious it’s going to....” “.....not very promising”. The phrases they are using are persuasive, the speakers are trying to lend authority to their ideas. If group think and primus inter pares effects are significant then these expressions become powerful narratives that are difficult to distinguish from the truth. The use of humour permits the articulation of ideas that the speaker has considered but invites judgement that the proposition is implausible. They return to the idea of a fuel leak. The learners have an initial intentionality about the cause being a fuel leak. They are seeking confirmatory evidence and when anything contradicts that intentionality they look for ways to dismiss the contradiction.

A number of propositions are considered and judgements of relevance or factuality and hypotheticality are applied. They have no data relating to the mass of the plane during the crash and so the airplane load is quickly dismissed as irrelevant or insufficient. The discussion turns to a potential evasive manoeuvre by the pilot and visibility of an object in the flight path. The flight recorder data indicates there were sudden and dramatic changes of attitude and loss of a large mass. A number of causal and counterfactual judgements are made in assessing the proposition. In the final part of this meeting the issue of the fuel loss is unresolved. The fuel leak is still relevant and they have judged that the loss of mass and the leak are related and relevant composites of the problem space even though they cannot envisage a fuel leak big enough to lose several tons of fuel in a few seconds. The propositions are articulated dissociated cognitions. They have not been able to find other evidence or make any mediating judgments of causality that would confirm or eliminate this causal relationship. The original heuristic judgement of causality remains dominant though they have considered a large amount of information that could contradict the idea.

5th and Final of Group 1 on 26/11/2013;

Five members were present, four actively engaged in activity with PC's and one passively engaged. This is the last group meeting prior to the presentation of their findings and conclusion. They propose that a debris field report would have produced conclusive evidence. The phenomenal field throughout was largely heuristic though after week 6 the discussion is populated with propositions of a more rational nature.

Noticeably they continue to intend a problem space by considering the coherence of the arguments rather than investigating the validity of the proposals they are making. This can be seen when there is a hypothetical judgement regarding the relevance of a debris field report. However, they did not make a request for this information due to the lack of time left before the final presentation. A debris field report could have provided conclusive evidence. This was a heuristic judgement of absence and hypothetical judgement of the value of the information. They have now constructed another disjuncture regarding structural failure for which they have to find a rational (or at least plausible) explanation. They have concluded that the leak alone would not account for the sudden loss of mass, this is a judgement of factuality on the sufficiency of evidence. Their knowledge of the ATC reports show another military aircraft in the flight path that they judge from flight recorder data to have resulted in an evasive manoeuvre severe enough to have caused a catastrophic structural failure. This is also a judgment of factuality. This conclusion is very close to the result anticipated and required by the tutorial team.

Group 1 Final Presentation Video;

In their final presentation which was recorded on video, they refer to a finding in the Safety Investigations Board report that a fuel seal had not been replaced as recommended and a batch of bolts on the ram weight balance were 'poorly tempered'. The embrittlement of the bolts would have resulted in them failing at a lower stress. Their conclusion was that the loss of mass was actually the engine breaking free due to the stresses from a sudden manoeuvre. This conclusion is very interesting and is explained below. They have correctly deduced that there was a sudden loss of mass and attributed it to part of the airplane breaking off. The matter of the tempering of the bolts however is a confabulation where they have fabricated convenient evidence. No such information is given in the brief. They have judged that there must be a rational explanation for something breaking off but they make a judgement of factuality that without a specific proximal cause there isn't sufficient evidence to make the claim. To resolve this cognitive dissonance they had to invent 'evidence' to make their narrative content coherent. It may be that bolts in different batches will not be identically tempered but that variance and whether it is statistically significant could be established empirically whereas they have assumed it without evidence. A heuristic class of judgments have overruled any potential for rational judgements because they lack knowledge on structural failures and the effort for rational judgment is too great within the short time frame. Given the age of the aircraft the more likely and in this scenario correct explanation is fatigue.

5.2.2 Participant Group 2

1st Observation of Group 2 on 15/10/2013;

Their first tutorial activity and five of the group are present, there is little dialogue and students are working in pairs information seeking using PCs and researching the Airworthiness Directive for airworthiness and compliance requests. There is a general unfamiliarity with some vocabulary and acronyms commonly used in aerospace industry. The research activity is wholly directed toward understanding of terminology at this stage. The initial problem space is too large and ill-defined for these learners to 'bound rationally'. It is full of data that they know may be useful but upon which they cannot apply reason until they understand enough of the phenomena presented to them to make any of the fundamental judgements about it. At the point that they think they know the phenomena they will begin to exercise all the discriminatory judgements and then judgements of relevance and composition are made to determine whether the phenomena comprise a coherent problem space on which they can work.

2nd Observation of Group 2 on 22/10/2013;

This is the second tutorial activity and the students have prepared and are presenting a video of a news flash about the air crash. In a reflective precis, three learners reported that decisions were made jointly by the group and that no one individual had made a decision that was significant in the development of the video. One however had judged that 2 other team members had made the most important decision to give the news flash a 'BBC flow'. This student felt that this decision "made the whole video fun to make and allowed the information to be delivered fairly easily". The same student disagreed with the addition of a BBC news desk intro as they considered it unnecessary. Two others did not disagree with any of the decisions while one other disagreed with the same person playing the roles of both reporter and eye witness and claimed this was unavoidable due to a team member not wanting to be on camera.

Similar to the first group, by framing the presentation in the style of a BBC news flash they have exercised an initial analogical heuristic judgment of appropriateness about the bounds of the problem space and its composition. This imitation has avoided a lot of cognitive effort in defining the problem space from a position of no knowledge. They have made judgments of similarity, membership, discrimination all of which are informed by the way they have experienced similar phenomena. Judgments of value emerged when asked about who made the most important decision. Judgments of value may be rational and quantifiable or heuristic. It is quite possible that students may have no particular experience that a judgement is pivotal but in judging that all decisions are equitable they avoid the cognitive effort of being categorical. One student credits two others with having made a pivotal decision and in so doing makes a value judgement about the decision, a judgement of appropriateness about the judgment of the others and a counterfactual judgment about the effects of the decision. Questions about alternative decisions and impacts elicited statements that exhibited judgments of value and composition, hypotheticality and instrumentality.

3rd Observation of Group 2 on 12/11/2014;

Five members of the group are present at a timetabled tutorial, their activity is centred on use of PCs. There is some discussion but too low to hear. I prompt them by asking where they are in their project this tactic generally produces a cascade of opinion that elucidates their current thinking.

> "At first I thought it was too difficult - the amount of information we had to cope with."

This heuristic judgement of measurement gives an indication of the way the learner perceives the complexity of the problem space and it is also a judgment of their own ability to process the information. Problem space theory predicts the problem solver will reduce the problem space to manageable proportions. This task is difficult for a learner with little experience whereas an expert would perform the reduction in a fraction of the time. The difference for the learner between this part of the project and the news flash cameo is that in the former case they have experience from which they can reduce the problem space by analogy. Learners in this group (and other groups) have from the outset considered the proposition of the airplane running into a flock of large birds a valid one and there is some data that would suggest the possibility.

> "Bird strike? I'm not sure about that but two of the girls are sticking with that idea."
>
> "There is a control tower report of Canada geese and they are quite big."
>
> "They didn't see the plane in the fog and the aircraft is not at high altitude so they can reach it."

Holding onto this idea suggests they have judged by inference that the relationship between the explanation and the airplane crash to be causal and also factual i.e. this is sufficient evidence. To these students the location and sequence of the phenomena appear coherent. The reasoning is heuristic and until they find further evidence to make the argument unsound they cannot change their view. Other students in the group are still forming their hypothesis.

> "We discounted some of the eye witness reports there is some variance and they don't link up."
>
> "Another airplane hasn't been reported despite witness statements."
>
> "Looks like an engine falling off - part breaking off but there isn't enough fire."

Eyewitnesses reported seeing the aircraft break up before falling. The witness statements do not appear coherent and this will affect their judgements of appropriateness and relevance. There is in fact a report of a military aircraft in close proximity but these students do not yet appear to have found the information.

> "The autopilot was replaced - they decided to fly despite lights not working."

A statement of fact put forward as a proposition.

"M isn't convinced but unless he has an alternative argument!"

Unable to convince a team member of the bird strike argument they are waiting for them to develop an alternative hypothesis. This is a judgement of appropriateness about the individual. There is also a heuristic attribution that the person is unable to provide other conclusive evidence.

> "The final presentation is about information handling not just the result."

The students are aware that some of their marks depends on more than just the outcome. As the potential of not reaching a successful joint conclusion becomes more imminent they feel a need to address the disparity. This statement about the final presentation is a judgment of instrumentality or means end adjustment.

4th and Final Observation of Group 2 on 26/11/13;

5 group members are present. This is the last meeting before they present their findings and conclusions. Now the debate rests between two members who have judged the cause to be an evasive manoeuvre to avoid a harrier jump jet and the remaining three who still think the crash was caused by a flock of birds. The only aircraft fault they judged to be serious was the autopilot but this was replaced.

> "We discussed these propositions at every meeting and during the flight simulation."

This is a judgement of counterfactuality. There is also resignation, an instrumental judgment that appropriate and sufficient action had been taken.

> "We'll present both hypotheses - there is no definitive answer."

There are judgements of appropriateness and factuality in this last statement. For this group the problem space is divided. Two possibilities exist and have the same validity and even though they have started at the same point and become aware of the same knowledge, the available information has been judged differently. Heuristic judgments can overwhelm rational decision making when information is absent or not acknowledged (Khaneman 2011:81,85).

5.2.3 Participant Group 3

1st Observation of Group 3 on 15/10/13;

Description of activity is given in appendix 14.

2nd Observation of Group 3 on 22/10/13;

Five team members present their newsflash. Each team member gave a reflective precis of their remembered experience of the development. The team were making decisions about the content of the newsflash that involve judgements of relevance, composition and appropriateness. This is the only team that assign an identity to the eyewitnesses, noticeably one is an engineer with specific knowledge. This representativeness heuristic increases the perception of reliability of the statement made by this witness. Other information included about the geese and autopilot would not have been released in a newsflash at this time and according to the delivery outline would not have been available to the students before the presentation. The students appear to have intended a problem space in which the solution depends on finding a technically preferred causality from the failure of engineered systems. This is a heuristic judgement of causality and relevance. A look at data distribution for air crashes between 1950 and 2010 shows on average 60% of all air crashes were attributed to human error (largely pilot error) and only 20% to purely 'mechanical' failure (source:http://www.planecrashinfo.com/cause.htm-accident statistics. 2014). This does not preclude the possibility that the cause is purely mechanical and there are no human factors however it does indicate that the current judgment about the nature of the problem space is founded on an intuition and base rate neglect and not on the probability of a certain category of evidence.

All of the reflective precis show that the students main decisions were about filming location, content and roles. When asked who had made the most important decision three of them stated that decisions were joint and of equal importance and two identified one team member as making the most important decision.

> "C because he edited the video."
>
> "C who chose to edit the video undertaking the most difficult role."

These are judgements of value and counter factuality. In counterfactual judgements hindsight bias is nearly always present to some degree. It is part of normal human cognition to under rate the contribution of others compared to oneself. Attributing superior value to the contribution of a third party is much more unusual and the recognition of that utility may stem from the salience of a particular memory of the experience. A discussion on task delegation probably took place and it is possible that only one person volunteered for a task that they were all very reluctant to take up. Judgments of counterfactuality and instrumentality feature in reflective work. Four of five reported disagreeing with the decision to film the newsflash the day before presentation, and unsurprisingly expressed the opinion that they should have begun filming earlier! It seems there were few options for filming days as one student stated the reason for the late filming was that they were unaware of the deadline until Thursday (four days before). They stated that they would manage their time better with future projects.

3rd and Final Observation of Group 3 on 12/11/14;

This is the last observation made of this group before the final presentation of their findings and conclusion. They discuss a number of propositions about the flight of the aircraft prior to the incident and the aircraft levelling out.

> "We know what the plane does but we're still working on what happened."
>
> "Which one is longitude east to west or north to south?"
>
> "It's climbing to 7000 feet radar contact was up to 3000 feet. Using the black box data we can use MATLAB to compare it with the CVR."
>
> "How much time elapsed? The CVR of the pilot is "What are we into? We're stuck in it!"
>
> "Is this a tail spin?"
>
> "We should look at the air and ground speed just in case they didn't stall or something"
>
> "140 knots - that's quite low." I don't know ground track angle, I'm just thinking about the implications."

The judgments are predominantly of measurement with some judgements of comparison and inference. At this moment they have been unable to attribute the cause of the crash to a specific mechanical or systems failure.

5.2.4 Participant Group 4

1st Observation of Group 4 on 22/10/13;

This team have made similar approaches to the problem space as the previous cases in that initial judgements for the newsflash are of relevance and appropriateness and overall judgements of composition. A number of the judgements however appear qualitatively different. Whilst there are judgements of absence of critical information (factuality). The judgments of relevance of some information and hence composition of the newsflash content may be questioned. For example the use of technical props is unusual in a newsflash to the general public. The gag reel has no place in a disaster news flash. It does make use of humour, however and possibly they found the exercise a little stressful.

2nd Observation of Group 4 on 12/11/13;

> "We haven't been working on it to be honest."
>
> "There's been no progress they're not taking it seriously."
>
> "I think it's a stall or a bird strike but they are dismissive."

The above three statements were made by the sole female in the group. These are her experiences of the way she perceives the group (in this case the others) is functioning. She works on one side and is not physically surrounded by the group. She perceives a lack of action but does not appear to recognise that may be due to her 'displacement' from the main group activity. There are two important judgements of intention attribution. The first occurs in the statement "They're not taking it seriously." This potentially has more meaning than just her perception when viewed in the context of the news flash gag reel. The second one occurs in, "I think it's a stall or a bird strike but they are dismissive." Here she judges them to be uncooperative and possibly also judged them to have a lack of judgement (appropriateness) about the availability of evidence. Intention attributions may arise from subtle cues in the behaviour of others and are vital to safe and efficient socialisation. This heuristic can be quite accurate. On the other hand many instances of this type of judgement can be subject to attribution bias. Not all actions are intentional and observers tend to neglect external influences that are not visible in a situation.

I went and observed the other team members who are working in a cluster.
I prompted them about where they are with the problem.

> "We've got a few ideas but we need the evidence to support them."
>
> "The maintenance report shows an autopilot failure."
>
> "Structural damage, wings or flaps but we don't have evidence."
>
> "Read about the leak? yeah, but it checked OK."
>
> "It could be a potential cause."

With the exception of the maintenance report comment, the judgements are all heuristic. The group were looking for a technical cause, there is by now a lot of technical information available and in defining a potential problem space they have made the judgement that information relevant to this domain will provide a causal relationship. To date however they have judged the information to be insufficient to establish cause. Lacking evidence (by admission) suggests the epistemological status of their intended problem space is really no better than the one they have dismissed. Therefore the judgements about the composition of the problem space are probably subject to the heuristic biases of representativeness and base rate neglect (Khaneman 2011:88)

> Have you held any other meetings? (*Prompt from me)*
>
> "No! can't get everyone together but we discussed when we did the video report."
>
> "Geese!"
>
> "Not a group still have this in mind! Come on!"
>
> "How unlikely is it to get both engines out?"
>
> "It says a flock of birds not one!"
>
> "So what?"

In this exchange there are more heuristic judgements. There are judgements of counterfactuality and instrumentality about the difficulty of arranging meetings. One of the males appears primus inter pares and is quite vocal, he makes a heuristic judgment of probability, dismissing the idea of a bird strike by 'argumentun ad populum' fallacy in reasoning. There are no rational grounds as yet for rejecting the proposition however, it is just not coherent with the result they expect. In this may be seen that the intention attribution by the sole female member could be a reasonable assessment.

> "It's a human error."
>
> "We are now checking the black box data."
>
> "It's not geese?"
>
> "Possible but unlikely - the autopilot was changed in the last 24 hours but you'd have to try it out, also the plane stalled and a flock of birds doesn't do that."
>
> "We need to make a decision, write down and compare and look for the best evidence, eyewitness, logical and say why we go for it."
>
> "The plane flew after the exam but it shouldn't have. It's a human error, something to do with the autopilot."

In this last segment judgements about the composition of the problem space are still heuristic. Most of the team continue to make further proposals but do not propose any specific methods by which the validity of their propositions can be verified. One team member judges the need for evidence of a particular type and judges that the best way to proceed is by judgements of reference and comparing 'evidence' If this proceeds it could lead to a solution by representativeness based on the coherence of each presented scenario rather than a rational assessment of the actual cause.

3rd Observation of Group 4 on 19/11/13;

Description of activity is given in appendix 14.

In a brief dialogue they reiterate the events of the air crash but they are having difficulty in judgements regarding discrimination between effects and causes and the relevance of some information. There are some judgements of factuality i.e. they think they have enough evidence to establish cause. Judgements about how to proceed are of composition and practicality. In hindsight they believe they have not changed from their original position though previous observations would suggest that they have considered a number of options. Cognitive mechanisms are adept at creating coherent stories. When events spring to mind readily with no apparent contra-indications the observer is increasingly confident of their reasoning but confidence is no measure of validity (Khaneman 2011:239).

4th Observation of Group 4 on 26/11/13;

There were judgements of practicality regarding the final submission of their work. Their final judgement on causality remains the same at this point. They make a judgment of inference that a control surface had jammed as a result of an evasive manoeuvre and the airplane became uncontrollable. This scenario appears coherent to the students however, there is no flight recorder evidence that any control surfaces jammed and they neglected the data that indicates there was an abrupt loss of mass.

5.2.5 Participant Group 5

1st Observation of Group 5 on 05/11/13;

At this point in time the problem space is still relatively undefined. There is a transition in thinking between heuristic and rational phases. The judgements related to what belongs in the problem space are heuristic judgements of composition, relevance and coherence. These however are made up of rational mediating judgements pertaining to discrimination and other judgements of appropriateness, practicality, measurement and factuality about the information given through the experience.

2nd Observation of Group 5 on 25/11/13;

The learners were beginning to build networks of information, positing hypotheses and causes. The dialogues that they exchange build narratives and the one that will affect the culminating judgements of causality most will be the one that appears most coherent. Coherence directly affects their level of confidence in their judgements and any information that contradicts the coherence will be ignored. The discussion has some degree of detail, the learners in this are beginning to qualify their reasoning.

The description of the observation is given in appendix 14. Learners exerted a number of judgements of analogy, reference and measurement with culminating judgements of hypotheticality, causality, factuality and instrumentality. This group moved to a much more rational problem space and have begun to consider propositions on the basis of the evidence they have uncovered. One proposed an empirical solution by using the flight simulator, but when the simulation was performed they found that an engine failure was inconclusive.

4th and Final Observation of Group 5 on 05/12/13;

In this last observation we can see that despite the tendency to rational thinking and the qualification of propositions and arguments a narrative coherence took over and the culminating judgement was almost entirely heuristic The group have rejected salient and significant information from the flight recorder that should have compelled them to reconsider their argument. These accounts of judgement appear complex but from the following quote by Khaneman (2011:81) it is possible to gain some insight into what is happening.

> "Understanding a proposition must begin with an attempt to believe it were true. Only then can you decide whether or not to un-believe it. The initial belief is a function of system 1 which constructs a best possible interpretation of the situation. Even a nonsensical statement can evoke initial belief. When system 2 is otherwise engaged you will believe almost anything"

5.2.6 Participant Group 6

1st Observation of Group 6 on 15/10/13;

It is early in the project and at this stage the definition of the problem space especially for someone coping with an unfamiliar and new problem judgement is almost entirely heuristic. The first comment reveals the student has made an intuitive judgement of relevance that is incorrect due to cognitive bias. There is no connection between the time a tutor spends in talking about a maintenance report and the significance or validity of its contents. This learner is applying a heuristic judgement about the validity of information in the belief that he has had some subtle clue to its relevance that will significantly reduce the problem space even though he cannot see anything salient.

This is a representativeness heuristic. In attempting the rational judgement of assessing the validity of the contents of an extremely complex document his cognitive mechanism has substituted and answered an intuitively easier question which might be put, “Does the attention paid to this document by an authoritative figure underline its importance?” It is possible that the learner also made an intention attribution incorrectly believing they had detected a subtle psychological cue that the tutor intended this situation.

Two students engage in a brief exchange to confirm their understanding of some information and make judgements of analogy and similarity. The next statement is a judgement of practicality. In the last sentence he dismisses some information in the report as inconsequential. This is a judgement of instrumentality but another representativeness bias is at work here. There is a tendency to try to predict the future state of something based on its current state but a better indication of potential failure would be records of the frequency of failures of different components so in fact he is neglecting base rate data. A component or system that is reported OK now could later fail in service and in a retrospective analysis it is probably better to seek information on the failure rate data distribution and make a judgement based on that.

2nd Observation of Group 6 on 12/11/13;

Description of activity is given in appendix 14.

The learners exerted judgements of measurement, practicality, relevance, factuality and causality. There were also judgements of absence or coherence.
The team were struggling to explain the loss of mass from the airplane. The leak wasn't large enough to lose so much fuel in a few seconds but the fuel loss was one tangible piece of evidence.

3rd and Final Observation of Group 6 on 05/12/13;

Four of the team make their presentation. The presentation was structured and comprehensive beginning with the incident details and details of the flight and ground crews experience and qualifications. They summarily dismissed the eyewitness accounts except two, one from a retired engineer and another from a flight engineer. They note the aircraft was loaded correctly and refer to the Flight Recorder analysis where they used excel to generate graphical outputs. The attitude of the aircraft is mentioned together with loss of starboard engine power and fuel loss. Their culminating causal judgment of the crash is that it was as a result of the loss of the starboard wing caused by an explosion of leaking fuel.

Their judgement of the eyewitness reports involves a rejection of all of the statements except those from professionals. This is a heuristic judgement of relevance and contains a representativeness bias. Representative biases may be correct, i.e. people who behave friendly normally are friendly. Similarly engineering experts are the most likely to know about engineering problems. The issue here being that experts are not necessarily better observers nor more inclined to re-activate more accurate memories of their experiences. The wing did in fact break off but not from an explosion as they thought. There is however a rationality to this causal judgement and the relevance of the fuel loss to the wing loss can be established in a coherent narrative.

5.3 Semi Structured Interviews

Three semi structured interviews were held within a few days of the end of the project with the aim of eliciting further detail of the project team work from the perspective of one of the team members. Each interview was manually recorded and lasted approximately thirty minutes. Simple prompts were provided to elicit responses but the direction of the interview was left as far as possible to the inclination of the respondent. These reflective exercises usefully reveal some personal and emotive aspect of coping with team member interaction as well as processing a large amount of diverse information on which to exercise judgement. The interviews are presented in appendix 15 as they were given, as descriptive passages in keeping with phenomenological enquiry. I have not selected particular parts in any order in which to illustrate particular aspects of judgement. Interviews are useful in giving voice to counterfactual and instrumental judgements in hindsight that are not always evident during action and remain latent if expression is not encouraged.

5.4 Students' Recollection of the Learning Experience

5.4.1 Perception of Conflict

2 of the interviewee's had memories of some degree of conflict between team members. The 2nd interviewee makes an intention attribution of uncooperative behaviour about other team members and a judgement of instrumentality that her own role was significant in moving the team forward.

> "The others had been asked to chip in but two didn't input to the presentation and one didn't help us at all."
>
> "In the sense that people pay, but I'm not the only one. It was unnecessary stress, I felt the group volition depended on me."

her particular team sat in different parts of the tutorial room for the whole of the project and it may be that a cohesion and willingness to function together was not realised.

The 3rd interviewee also makes an intention attribution when she claims

> "They literally can't be bothered."
>
> "In the beginning we all bounced ideas, toward the end the two guys left it to us."

It would only require one negative experience to convince the observer of intentionality. The attribution error is the rejection of the possibility that some external influence might have affected the attendance or performance or attitude of the other person. In her view poor interaction is judged instrumentally to be inevitable given the learner's circumstances.

5.4.2 Perception of Contribution and Team Effort

Team effort was an issue of great importance to students who attributed various levels of cooperation or activity to others in their team. The teams were selected by the tutor and the extent to which the teams functioned effectively varied significantly. The learners do not receive any coaching on team skills before beginning this project.

Learners often express negative sentiments about team working. The remembering self emphasises negative memories as though they are all that was most important of experience.

The first interviewee expresses his feelings about their final presentation and factors that affected it. These have become the most salient memories of his experience. The technical issues are transitions in the experience that are given. They are invariable and waiting to be discovered. On the other hand the socio-technical issues that were realised by team action are those that are remembered as affecting the outcome most, even though he cannot quantify the extent to which the lack of input was deleterious to it. His first statement is a judgement of value and appropriateness it is quite subjective. It doesn't appear however that hindsight bias had much impact on his subjectivity or he'd have claimed the outcome was as he thought it would be. Subsequent statements qualify his feelings about why he felt negatively toward the potential outcome. These are judgements of counterfactuality and instrumentality. Allowing for any hindsight bias that would cause him to exaggerate his contribution compared to that of others, he actually identifies other pro-active people. There is however some justification in his view that some team members weren't particularly active. When asked about the most important decision his thoughts are still directed at actions directly affecting the quality of the outcome viz the final presentation. He doesn't pinpoint any particular decision or judgement about the development of the actual solution. He expresses a satisfaction with the solution they developed that reveals judgements of appropriateness, factuality and instrumentality. He said,

> "It made sense to us,"

The second interviewees initial recollection of the project focuses on the dynamic and interaction of team members. The reference to the tutor putting groups together is both counterfactual and instrumental. It implies that if they'd had a different group things would have been much better or easier. In her intentionality it justifies the difficulties they ran into and the relative success or lack of success with coping mechanisms. When asked "What would you do differently?" she replied that she would choose the group. It was noticed that she spent a significant amount of time working alongside two students from another group. Confirmation and representativeness biases convinced her that a team made up of these selected collaborators would have done a better job.

The process may have been more convivial but these potential collaborators from the other team actually fared no better in their answer. They concluded correctly, that the wing was broken off but erroneously attributed it to an explosion. This result is illustrative of the potential problems caused by group think and the *Primus inter Pares* effect on efficient and rational team working, see 2.2.3. Video evidence of her part of the presentation was confident and articulate, giving the correct answer that the starboard wing tore off as a result of stresses caused by the evasive manoeuvre. However, since the presentation put forward a number of plausible arguments it was not possible to know exactly who arrived at the correct causal judgement.

The 3rd interviewee's memory also focussed on the team interaction. Her counterfactual judgements of team work were quite positive. She reported that their solution is based on a number of facts. However their problem space definition and conclusion was largely incorrect. Their intended problem space ignored flight recorder data that should have changed their world view. Her group spent a long time trying to understand terminology and technical issues.

> "The most difficult aspect was having to read all the technical reports without knowing what some of the things meant."

Unable to make sense of the information, heuristic mechanisms develop a likely scenario. If rational mechanisms can't find or use other data to overwhelm the heuristic narrative it becomes entrenched. (Kahneman, Slovic, Tversky. 1982:118) (Kahneman 2011:114) This becomes clear later, when she makes the following statement.

> " the birds was the one thing that made sense together with some other things."

She did not make any reference to any particular approach, organisation, memorable experience or significant idea that occurred during the course of the project. If they considered other accident statistics as guidance it could have helped them reduce the problem space very efficiently, otherwise the availability heuristic lead to serious errors. They initially concluded that the flock of birds was significant and built a narrative around that event failing to account for the loss of mass. Finally there was the counterfactual judgement that they would probably not make any changes to the way they went about the project.

5.5 Case Study 1 Conclusions

5.5.1 The Technical and Socio-technical Demand of the Problem Space

The technical demands in this project are moderate. There is no requirement or necessity for detailed or advanced mathematical and mechanical analysis, structural or materials knowledge. Numerical data can be processed by software for graphical interpretation. While the learner is invited to consider human factors in eye witness reports, air traffic control reports and recordings of the pilot and co-pilots voices there are no severely conflicting demands between competing social, regulatory or political constructs that would exercise judgement in complex or wicked socio-technical scenarios. I conclude that the specification and additional information present a problem space that has both technical and socio-technical attributes that present moderate technical demands and are relatively well defined. Fig 3. shows the demand plotted on the problem space map. This plot is subjective but indicative of the scope of the problem in terms of technical and socio-technical demand. The problem space is largely limited to the information provided but had the potential to create disjunctures at various intervals by providing information that challenged the intentionality of the learner to provide a rich environment in which to exercise judgements. In some instances learners extended the problem space by introducing propositions about necessary information and methods to test their reasoning.

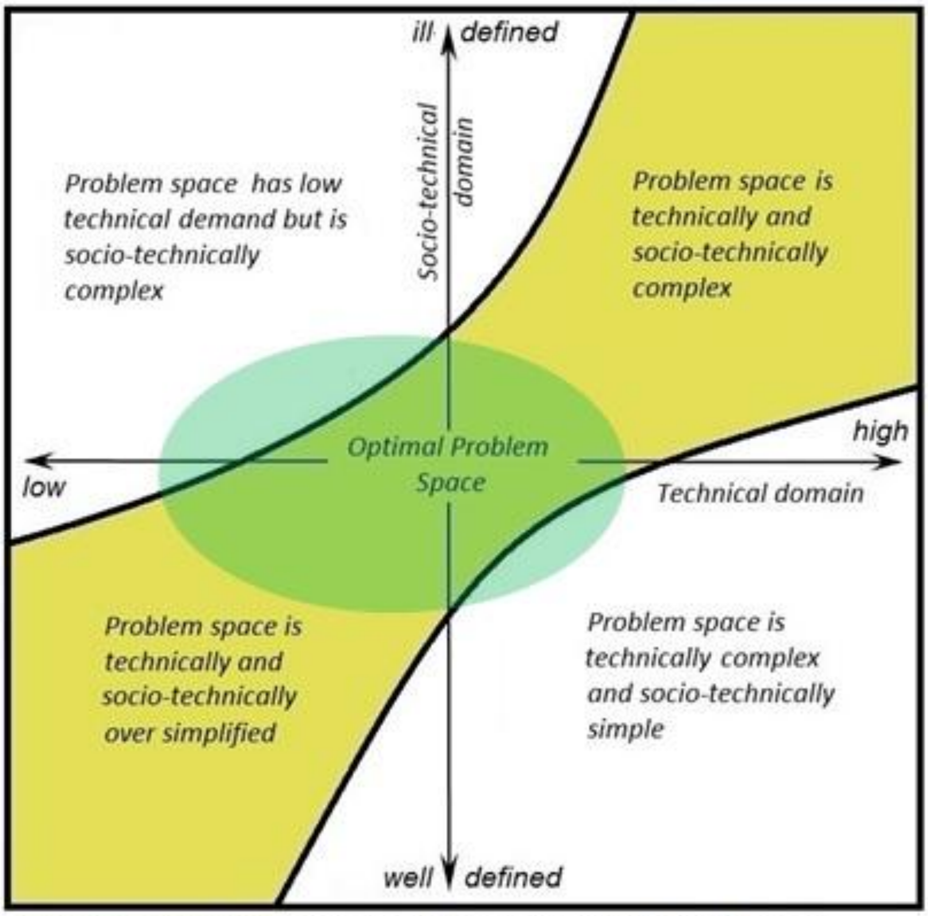

Fig 3. First Year Aerospace Crash Investigation Problem Space

5.5.2 The Learners' Experience of making Judgements

Observations of group activities indicate certain phenomena present themselves that exhibit a similarity in the intentionality of the learners. Several aspects in the development of the solution are notable. The main disjunctures constructed by the learners relate to the connections and validity of the arguments around a number of factors. These appear to have been:

1. The weight given to some eyewitness reports
2. Air traffic reports on the presence of a flock of birds.
3. The conflicts between the rapid loss of mass and fuel loss when the reported leak was negligible.
4. an evasive manoeuvre and a possible impact.
5. Pilot error

6. Control systems or control surface failure
7. engine failure
8. The plausibility (or lack of) of a wing failing under stress

All of these issues may or may not be relevant to the problem. The learners defined the problem space by constructing plausible explanations around the information provided. Most of those judgements resulting from these disjunctures were heuristic and when the learners had intended a problem space and a coherent explanation they began to develop their arguments resorting to more rational reasoning.

In the early stages the learners made heuristic judgements about what was or was not relevant to the problem space. This initial problem space definition depends upon any knowledge the learner brings to this process and any information they have been presented with. The learners intended a problem space from the experiences and knowledge that were most plausible The influence of the availability heuristic would mean the learner tends to view the experiences most easily remembered as being the most plausible. As the problem space was reviewed the learners made successive judgements that either tended to confirm their position or create a disjuncture that forced them to reconsider their position. Unless a disjuncture occurs during reasoning there is no imperative to change their original heuristic and they will take it forward with increasing confidence.

A large quantity of technical information was provided, typical of the breadth of information available to crash investigators, some of which was not directly related to the cause. For some teams, particularly in the early stages, this factor was persuasive and they intended a problem space in which the cause of the air crash was solely due to a failure of an engineered system or component.
At some later stage they revised the problem space so that the mechanical failure is proximate and an extreme and sudden evasive manoeuvre is the ultimate cause. None of the teams extrapolated this to human error in air space control causing the evasive manoeuvre.

The learners intentionality can be affected by subtle effects. In one instance we see a learner drawn to invest effort in searching through the aircraft maintenance report for anything of significance. This was the result of an intention attribution. He noted the tutor presenting the maintenance report had spent some time on the process and concluded the reason he did this was because it contained significant information.

The learners did not negotiate and develop the problem space in a linear process that moved sequentially and logically from proposition to another. Rather the process is iterative in which the value of particular propositions are considered and judged by the learner whose understanding and knowledge of the problem changes from a state of uncertainty to a state where conditions for evidence or coherence are satisfied. Concepts were continually revisited and re-judged in the context of any new information, emerging patterns and networks of previous judgements. In protracted discussions the team members deplete due to the cognitive load. This can occur several times in an hour and the depletion point can be discerned from the sudden occurrence of off-topic comments.

5.5.3 Diversity of Judgements

From the transcripts it can be seen that there are numerous situations where judgements of factuality occurred as mediating judgements culminating in a judgement of causality. Judgements of factuality hold that certain knowledge is sufficient evidence for certain conditions to be met or decisions to be made. From the transcripts, judgements of factuality appear complex and three distinct modes can observed. Firstly, learners exercised judgements of factuality about clusters of all the given information (the phenomenal problem space). Additionally in some cases, it can be seen that learners exercised judgements of factuality about ideas they had generated (the noumenal problem space) by judging the absence of useful and relevant information. One team recognised the absence and validity of having a debris field report but the disjuncture resulting from this judgement of factuality was not sufficient to compel them to acquire the information. Finally, a number of judgements of factuality were heuristic and focussed on the coherence or how plausible the information narrative appeared as opposed to the validity of the information content.

Overall, there is some difference in the cognitive load inherent in judgements of factuality that appears to be dependent upon both the complexity of environment in which they are exercised and on the way groups of individuals develop and resolve the problem space. Judgements of factuality are also culminating and as such are dependent upon other judgements such as discrimination, value, measurement, appropriateness and relevance etc. The judgement of factuality may present in combination with judgements of counterfactuality and instrumentality, the latter being more likely to occur in reflective work to justify decisions. Early stage heuristic judgements to reduce the problem space are not efficient in learners exposed to a problem for the first time.

From the transcripts it can be seen that they often lead to serious misconceptions that once judged to be coherent become intractable even when other evidence comes into the problem space. For this stage to become more efficient the learner must be able to construct analogies from experience or otherwise be able to recognise when heuristic judgements are likely to lead to error and correct them accordingly. The former route will take a long time if it relies upon the random and sporadic occurrence of learning disjunctures by which rules and analogies can be acquired. The latter would require additional learning directed toward the analysis of solutions and the adoption of a specific approach in thinking methods.

5.5.4 Analysis of Interview Transcripts

In the interviews, the interviewees are invited to consider their team project and essentially recall their experiences. Memory is not a recollection of facts or details. Neither is memory 'experience intact', but something elusive that can be tampered with by the individual reactivating them (Sokolowski 2000:69). Acts of remembering reactivate images, experiences and emotions that are as intense as the time they were first experienced. All three interviewees exhibit recollections of the project as predominantly human interactions that are unpredictable and uncontrollable. The contribution of others appears lacking or unquantifiable, their own efforts pivotal. The actions or withholding of action by others appears intentional while their own actions or omissions appear inevitable. Two of the interviewees stated that their conclusions made sense to the group. These are judgements of instrumentality but they also underline their reliance on narrative coherence when making judgements of factuality. I had expected that the learners would more readily recall relevant and salient facts about the decisions made by their groups. Their remembering self however re-activated more of the human interactions and even when prompted to think about the actual problem development they were drawn to the human issues. It is as if transitions in the knowledge states within problem space are forgotten in order to realise a conclusion and the students recollections of any of the transitions are of behaviours. This may seem surprising but a significant proportion of human cognition is evolved toward seeking collaboration and the memories of the way they experience others may be those that are most readily re-activated.

6. Case Study 2: Design and Construction of CNC Work-holding System

6.1 Introduction

The apprentices in this study, work for a company in the north east of England that manufactures high integrity valves, cable glands and hydraulic pumps for the oil and gas extraction industries. The apprentices attend a training facility one day a week to study for a BTEC in Manufacturing Engineering and to complete competences in 'Performing Engineering Operations' (PEO). The remaining days they work alongside skilled operators or craftsmen in a community of practice to learn the tasks necessary for them to become skilled. For a further 3.5 hours a week for a duration of 33 weeks in each year they are taken out of the workplace to participate in an enhancement programme. The employer's purpose of this programme is to identify individuals with potential for further development in technical grades or supervision. The enhancement programme extends over 2 years and ALL interventions are used throughout as the learning environment. The enhancement programme was developed and is tutored by me.

In the enhancement programme which was selected for this study, the apprentices were given the task of conceiving, designing and making a pallet work holding system to locate and restrain a component used in the manufacturing of their company product. The component had been considered from experience to be difficult to machine because current work holding practise limits tool access and can result in distortion. The apprentices were given the following project outline and specification via power point slides and hardcopies located on google drive. The apprentices engaged in this project had progressed from the foundation programme. There were four groups of three apprentices of mixed ability according to their foundation work scores. Each team was comprised of apprentices from different sections of the company. Group 1 was comprised of one female turner (CNC lathe operator) who was the team lead, one male turner and one male miller (milling machine operator.) Group 2 was comprised of 1 male miller (team lead) one male turner and one male fitter. Group 3 was comprised of one male miller (team lead), one male turner and one other male miller. Group 4 was comprised of one male turner (team lead) one male grinder and one male production engineer. The apprentices were supported by tutorials in which they were instructed in the development and use of project management tools during the first three weeks and in later tutorials on jig and fixture location on machine axes, clamping system mechanics, free body diagrams and CAD drawing. All of the apprentices have some experience in manual machining and use CNC machine tools as part of their everyday work.

6.1.1 The Project Specification given to the Learners

The project specification was given to the apprentices in tutorial via a power point. They are talked through various aspects such as project management and record keeping and encouraged to discuss and speculate on the kind of things they need to present to clients and company directors. The learners are also encouraged to maintain documents in an online repository and use online systems for communication. The outline project requirements and client specification are given in appendix 10.

Deadlines were imposed that allowed nine weeks for the design concept stage, seven weeks for the draughting stage and fourteen weeks for the final production stage. The learners are given a drawing of the component that the work holding is to be designed for and a standard routing report with machining operations. The company name has been removed from the drawing image for the purposes of research participant confidentiality.

6.1.2 The Scope for Judgement in the Project Specification

From the project specification and accompanying tutorials, the apprentices had to develop and construct a practical work holding system from an outline specification together with their own project management documents. The apprentices have a relatively open objective that has any number of viable solutions and are only constrained by their intuitions and research capabilities. Specific objectives, or learning outcomes are not given enabling the activity to lead the learning process so they are able to form their own bounded rationality of the problem space and develop any solution that can be tested against the specification.

There were three stages in the project each of which provide numerous opportunities for disjuncture and the exercise of judgements. Concept development takes place in the initial stage. The learners have some experience of work holding from their workplaces that is largely limited to vise work or clamping on tombstones and bolsters. There are few instances where they have encountered dedicated rapid fixing systems and the study of such systems is new. It could be assumed that the apprentices had few experiences from which to make judgements of similarity or analogy to define the problem space and had to define it wholly from the stream of new information they acquired. They were able to research and decide materials and speculate about different work-holding systems but the project management tools and mechanics and mathematics had to be taught by example. Over a period of nine weeks they discussed and sketched different ideas and then when they were in a position to prove their designs they incorporated a mechanical and mathematical proof of their ideas. At the same time they were able to put together their project documentation. They present their initial conceptual work and planning at the first deadline. The apprentices are not told what to produce but are left to judge what is appropriate, composite and relevant to each of these outcomes.

When the concept design stage had been approved they proceeded to produce CAD drawings of their ideas. It was found that although the apprentices admitted to some basic knowledge of AutoCAD they needed to review setting up model space, coordinate entry methods, annotation and projection. They were given up to 6 hours of intensive training in these skills before they worked on their own drawings. At this stage they produced a bill of materials for the stock they needed for machining including any specific tools.

In the machining phase, the apprentices had exclusive access to three, manual milling machines, three centre lathes, one CNC lathe and one 4-axis CNC milling machine together with all the necessary tooling. There were not enough machines for each apprentice to work on individually and some degree of organisation was needed on their part to manage and distribute the work between them. All aspects of machining were under their control and discretion including calculating the machining parameters and writing CNC programs. The teams were required to treat the project as a commercial exercise as well as a technical one. By having to work to deadlines and 'pay' for consultant expertise they had to exercise judgements that resolve conflicting issues such as confidence about the difficulty of the work and their own expertise and the risk of incurring penalties for failing to meet deadlines against the cost of hiring a consultant. This adds a socio-technical dimension to the technical demands of the project. They were required to observe strict confidentiality about their ideas and costs. It was anticipated that the apprentices would have opportunities to exercise a diverse range of judgements.

Typically in the initial concept stages they would be involved in discussion, using researched information, convincing convince others that propositions are sound or otherwise and exploring ways of visualising and expressing concepts. These activities require initial heuristic judgements of the problem space and mediating judgements of discrimination, composition, appropriateness, relevance, inference, value, reference, and hypotheticality as the space was continually re-defined. There could be situations when they would have to manage conflicting technical and practical demands and make judgements of difference, value, measurement, practicality and causality. Heuristic judgements of intention attribution would feature in their communications and negotiations to cope with each other's behaviours and ideas. At each end stage of the project they present their current progress, providing opportunities for judgements of composition, appropriateness, factuality, counterfactuality and instrumentality.

6.1.3 Data Collection Method

The apprentices were tutored by myself so that I was both participant and observer in the process. The largest proportion of available data was however taken from observation records and log book entries with a small number of interviews and records of presentations. Ninety nine opportunistic observations and records of the apprentices' activities and dialogues were made of the groups every week over a period of 33 weeks from 4th October 2013 to 13th June 2014. The apprentices also maintained log books of their decisions and activities each week giving a total of one hundred and thirty two log book records. Each logbook entry has three sections in which they recorded summaries of i) their intentions and work planned, ii) events that occurred and actual work completed and iii) a reflective assessment of their planning and efforts. To structure the presentation and correlation between log book entries and observation events, this study is written so that the experiences are given chronologically and each group is considered in the same time frame. The logbook transcripts, observations and dialogues are presented in appendix 16. Selected quotes from log book entries or actual conversations are given to provide actual examples of activities and dialogues that occurred during the observations.

6.2 Phenomenology of the Learners' Experience

Analysis of logbook entries for Group 1: 4th October to the 1st November 2013

From the logbook entry from the 4th October it can be inferred that they have performed the initial heuristic problem space reduction because they are now investigating the value proposition of different types of information that they have judged relevant to the advancement of the problem space. They have made judgements about the composition of the problem space including judgments of relevance, appropriateness and value that are almost entirely heuristic. Their intention to survey current practice involves judgements of hypotheticality, relevance and factuality.

The logbook entry made on the 18th October reveals they have moved on to consider technical detail. There is a sudden change of focus to the technical domain that appears to be more of an intuitive leap than a clear rationale. The fact that they do not continue with it suggests they had become temporarily depleted in their planning and costing efforts and had the intention to study some of the technical detail to see if it generated new propositions or leads to the discovery of other necessary information. The reference to "permit machining" indicates the possibility that an initial idea has been judged inappropriate because the set up would impede or prohibit cutting.

The log entry for the 25th October shows they have changed the focus back to the socio-technical domain They have made a judgement of factuality, that the current state is sufficient for now but the statement ‘Still a work in progress’ shows they still think they have further revisions ahead. There is a judgement of counterfactuality regarding the final costs and the accuracy of the initial estimate.

1st observation of Group 1 on 1st November 2013

From their accumulated joint experience of machining practice they have limited information and analogies from which they can intend a problem space and make judgements of factuality about the absence of necessary information. From the risk register however, they were able to make heuristic judgements of hypotheticality, relevance and composition that were valid and comprehensive about a diverse range of issues that they have to manage throughout the project. Despite having little concrete information they arrived at an unqualified but not unreasonable idea of the effort, time and potential obstacles to their project. Their initial estimate for costs is £21K. There is a degree of optimism in their reasoning. The reflective and evaluative sections of the log book are platitudes around team work and communications that are quite vague. They did not make any critical evaluation of their development ideas.

Analysis of logbook entries for Group 2, 1st November 2013

From the logbook entry made on the 11th October, the team determined the locating points first, exercising judgements of practicality, relevance and factuality since this information is required before clamping can be examined. On the 18th October exerted judgements of relevance, appropriateness and composition extending the problem space with concepts of mechanical systems that have potential for uses in clamping. Not all of their ideas are appropriate to the project specification. From the entry made on the 25th October, they planned to work on their project plan, revising costs and risk register, however they recorded their actual actions as researching different applications for clamping methods. There is no evidence that they resorted to a rational elimination or selection of mechanisms. Exercising heuristic judgements of value, and counterfactuality they have eliminated options that would have been difficult for them to implement.

1st observation of Group 2, 1st November 2013.

Their initial cost estimates were low and the effort and time for machining the fixture were very optimistic. Intentionality of the original problem space lacked awareness of some relevant information, in consequence they made heuristic judgements of value that were inaccurate. The discovery of other relevant information enabled them to make judgements of appropriateness, comparison, value and factuality about earlier propositions to compel them to reconsider earlier propositions and redefine the problem space. The decision to use a tombstone as the fixture is a judgement of analogy from experience rather than a judgement of appropriateness. The team lead operates a horizontal mill on which tombstone fixtures are common. The team have adopted this without challenge and the team lead may also be Primus. The decision could prove fortuitous since they have judged its potential to mount 2 components in one fixing operation and machine both consecutively. Had they relied on a trade case study for information they would have found that pallets are used in vertical machining operations and because they are lifted manually or by auto pallet changer they are kept small so the mass is as low as possible whereas even a small tombstone is heavy. They also considered altering the component in some way to facilitate ease of work holding. These intuitive leap of reasoning involves a series of high end heuristic judgements of appropriateness, practicality, hypotheticality and counterfactuality and instrumentality.

Logbook entries for Group 3: 4th October to 1st November 2013

From the log entry for 4th October, their discussion of costs leads to a judgement of factuality that they do not have sufficient evidence to proceed to a conclusion. The judgement is complicated by the intentionalities of the team members who perceive problem spaces with different cost implications.

From the log entry for the 11th October. The period of reminiscence from the previous week enabled them to re-judge the project costing. They will have made further judgements of appropriateness, relevance and composition, culminating in a judgement of factuality that the costing is complete at that time.

From the log entry for the 25th October. The team probably selected mild steel because that material is commonly used in one-off jigs and fixtures by their company and they made a judgement of analogy. They have now realised it can't meet the specification, indicating judgements of counterfactuality discrimination, value and appropriateness were exercised.

1st observation of Group 3, 1st November 2013.

Group 3's problem space definition had an unusual aspect Their approach was to consider a number of similar projects and by judgements of analogy, similarity and discrimination, to cost their project on the basis of a judgement of the data distribution. The case histories are not completely analogous and they have to re-define the current problem space at some point. However, resorting to data from case studies is a rather rational way to go about an initial estimate of costs and effort. They have made a judgement of practicality to provide mechanical design proofs after draughting. This heuristic judgement effectively ignored the chances of the design mechanics being wrong and the consequences of having to re-draught their machining drawings. Judgements of appropriateness, practicality, reference and factuality were exercised regarding the choice of material. This led them to make an innovative leap to depart from the specification and choose a specialised aluminium alloy for fixing. They judge this action to be appropriate and hypothetically justifiable to the client.

Logbook entries for Group 4 11th October to 1st November 2013

11th of October: The logbook entries by this team up to this point support my observations, they were however brief and superficial notes. The lack of detail potentially inhibits a complete phenomenological perspective of the important detail in their thinking. Their heuristic judgements defining the initial problem space are error ridden and will require major revision. AISI316 commonly used in their employment, cannot be hardened by heat treatment and their estimates of cost and the effort involved are very optimistic.

1st observation of Group 4, 1st November 2013.

This team had the greatest difficulty in initial problem space definition. Their difficulty in judging its composition and the relevance of necessary knowledge are immediately evident in the lack of breadth of the risk register. Their choice of material and clamping mechanism is a failure of judgement of hypotheticality, relevance and practicality within the context of the problem specification. Heuristic judgements of value and measurement were made about costs and effort without the benefit of even a vague plan of action that given their lack of experience would leave them completely susceptible to the planning fallacy. (Khaneman 2011:250,251)

2nd observation of Groups 1,2,3 & 4, 8th November 2013.

The problem spaces are still being defined at this stage. In teams 1, 2 and 3 discussion is driving the activity by introducing new knowledge and propositions. The learners make judgements of practicality, measurement and culminating judgements of relevance and appropriateness. Group 4 are not making any headway and need to generate or identify propositions on which to make mediating judgements of relevance, appropriateness, measurement to intend a state of knowledge that they can develop further. Moving from the heuristically derived early problem space requires cognitive effort to make judgements that are rationally founded.

3rd observation of Group 1 and team lead interview, 15th November 2013.

The team made judgements of inference and factuality regarding the validity of information sources. Acquiring shop floor anecdotes about machining times is probably as useful as calculating them using the standard empirical formulae. Similarly data distribution from the purchasing department will be as useful in predicting costs as online market information. System 1 thinking will avoid cognitive effort where it can and making a heuristic judgement by substituting a difficult question or task for an easier one avoids cognitive loading. If the data that they come up with is sufficiently accurate, the heuristic judgement will have been efficient. The decision to revisit location and clamping indicates they have made a judgement of factuality and the current proposition is insufficient to satisfy their intentionality toward the problem space. I observed their difficulties in making judgements of discrimination, appropriateness and relevance about applications of different types of cam. In consequence they made a heuristic judgement to examine the potential of over centre clamping mechanisms possibly in the hope this would prove less intractable. An intention attribution was made about the conduct of a team member. The potential attribution error is that his behaviour is deliberate when it may be his style of debate in the context of other external influences during the discussions. A counterfactual judgement was made about project management activity.

3rd observation of Group 2, 15th November 2013.

From experience they have analogies about work-holding and how it affects access to the work with cutting tools. A judgement of hypotheticality intends a potential problem space in which the machining sequence will present the locating and clamping options available. This line of reasoning relies on deductive judgements of analogy, practicality and hypotheticality. They have no direct experience of machining the component however and make the heuristic judgement of practicality that they can rely on anecdotal practice from the shop floor. By discussing machining 'difficulties' with operators instead of machining 'procedure' he knows something that the routing report cannot provide so the judgement of value to resort to anecdotal evidence may have provided 'richer' information. Bolting fixtures to a machine is a common practice, their decision to investigate it may be consequent to a lack of judgement of discrimination or appropriateness or a failure to understand the requirements of pallet systems. In the dialogue the team lead makes judgements of counterfactuality and instrumentality to justify work, team behaviours and intentions.

3rd observation of Group 3, 15th November 2013.

Their judgements of practicality are directed at engineering technical processes rather than management of the processes. Heuristic judgements of value and appropriateness are made in order to decide where effort is placed. Despite being told that the project management, group work and record keeping are assessable components, outcomes are cognitively important phenomena to learners that are used to being assessed on outcomes rather than processes. They have the same dilemma as Group 2 and need to understand the machining of the component in order that the optimum location and clamping will be revealed.

3rd observation of Group 4 and group lead interview, 15th November 2013.

Judgements of discrimination, relevance, composition and hypotheticality dominate their discussion on revisions to the project plan. The admission of more concrete machining data has influenced their judgements of practicality and value leading to very much larger figure for costs. The design is presently dominated by heuristic mediating judgements of appropriateness and analogy. The design process is skewed by heuristic judgements of appropriateness and practicality that one person can handle it on a CAD system. The selection of materials involves judgements of discrimination, measurement , relevance and reference. This group do not have a structured overview that links project objectives and discrete tasks through processes. For them the problem space is still ill-defined.

4th observation of Groups 1,2, 3 & 4, 22nd November 2013.

All the groups are working through their concept making judgements of practicality, measurement, discrimination, appropriateness and factuality. This leads to the discovery of new knowledge states and challenges the coherence of the concept components. Judgements of measurement, reference and hypotheticality alter their intentionality of the problem space and compel them to consider the validity of their design components and admit the necessity of change. The problem space they intend has become sufficiently complex to create compelling disjunctures and the urge to solve them. System 1 heuristic judgements will try to uphold their current problem space construct as an appropriate solution. The disjunctures created by the conflicts with system 2 rational thinking can enable them to unpick the belief that their current design is valid or it may sanction their heuristic thinking. In group 4, one group member was left to carry out some part of the work. This is a particular case of judgement of factuality about capability and trust. It is different to judgements of factuality about phenomena because we don’t experience people as objects. An object has attributes that persist across contexts and can be judged objectively. Judgements of personal characteristics are entirely heuristic and subject to a representativeness bias where capacity and trust is judged on visual personal attributes rather than actual performance data (Khaneman 2011:91).

There does not appear to be an explicit intention attribution in the dialogue. He judges the behaviour of the group member as being subsequent to external influences “listening to people from his department”. Judgements of measurement and value about the effort involved in a task effect judgements of appropriateness. The arguments from both sides are rationally bounded and system 2 thinking in both parties has entrenched their initial heuristic judgements so that neither side is prepared to concede. Unable to improve upon their rationales they outvote X and insist he fall in line with the original plan. This is a substitution heuristic. The dilemma is too difficult to resolve by rationale discourse so the question of who is right is substituted with an alternative question that is far easier to answer.

5th observation of Groups 1,2 3 & 4, 29th November 2013.

Group 1 is working through another iteration on work piece location and they consider various propositions involving judgements of hypotheticality, measurement and discrimination. The exchange on work piece mis-loading is a judgement of practicality whilst the statement on operator capability is a judgement of appropriateness. Acknowledging the requirement to include a poka yoke application is a judgement of practicality, appropriateness and instrumentality. Heuristic Judgements of measurement and appropriateness are applied to propositions about the size of the base plate and locating pins and a judgement of practicality about the fitting of dowels.

Group 2 are discussing the mechanics of clamping with their current concept sketches. At some point a judgement of measurement and factuality have been made and they realised that some changes have to be made for their cam to fit. They make a heuristic judgement of composition and factuality regarding how much work is left to do. I note they have overlooked limits and fits of mating components, and have not yet considered the mechanics of their design and the possibility it will compel them to revise yet again. I conclude their judgement is over optimistic.

Group 3 have arrived at a design even though lacking definitive information on machining practice, the problem space is imperfectly defined. They have made a judgement of factuality regarding machining procedure. A judgement of counterfactuality leads them to question whether that judgement of factuality was correct. A judgement of instrumentality justifies the need to seek further information to check their reasoning. Discussing various approaches to construction of the pallet and fixing of locating pins require judgements of practicality and appropriateness.

Group 4 has become dysfunctional. Lack of trust and conflict avoidance has resulted in low levels of cooperation. It takes nearly 50 minutes before they 'start' to work. Making judgements about appropriate siting of location pins is inhibited by not being able to make analogical or hypothetical judgements about the work coordinate system. They make heuristic judgements about the effort involved in making some parts and comparative judgements about the value of purchasing them.

The next observations are of an end of stage presentation on the 20th December 2014 in week 9 of the project. The observations are given in appendix 16. The total in tutorial time is now 31.5 hours for each group and additional work has been done in extra tutorial time. This presentation delineates the end of the conceptual stage of the project and from now on they will produce CAD drawings of their designs. Each group are observed presenting their first stage design solution. It could contain all, or some of the following:- Concept sketches of components with locators and clamping mechanism with approximate dimensions, free body diagrams and mechanics and materials research with an explanation of their rationale. In addition project management documentation and a costing for the work is to be presented as if to their own company directors. The learners were given no particular criteria to meet but are asked to judge appropriate content and style for professional presentations to both the client and their own company directors. After their presentations each group were given a stylised feedback sheet that included the 'criteria' by which I assessed the presentation as both their client and their director. The feedback enabled them to discover the kind of reaction they would receive from those audiences for them to reflect critically on their work in an attempt to make them sceptical about their judgements. Marks were not awarded solely for content or subtracted for omissions and errors but were also given for their judgements, approach and justification of their work.

Draughting Phase 10th January to 21st February 2014

After the initial concept phase of 9 weeks, the learners were required to produce drawings of their designs ready for machining. 7 weeks were allowed for this draughting phase. The apprentices claimed to have learnt to use AutoCAD 2013 as part of BTEC studies. It became apparent however that their facility with the system was not very good and some groups encountered serious difficulties in providing good drawings. Consequently a degree of intervention became necessary on an individual basis. Approximately half of the learners use the imperial system in their daily work and some groups began worked in imperial units and later changed to metric while others worked solely in metric. The component drawing provided in the specification is in imperial because it is part of a valve system destined for the American market. The initial choice to use imperial may have been an availability heuristic from work practices or it may have been an association with the client drawing. The change appears to be down to the realisation that the machine controls are all metric.

The standard of drawing was quite poor and several omitted significant details, there were also errors in dimensioning and precision. This was surprising in that all of the apprentices handle commercial drawings and have analogies to draw upon. It does however raise questions about their judgements of practicality and appropriateness regarding work standards and their capability. The groups were still struggling to calculate forces for free body diagrams and in consequence some final dimensions had not been realised before draughting commenced. The rise and displacement of a cam is dependent upon its angular displacement and eccentricity. All of the groups had difficulty in visualising this concept. The lack of information and uncertainty creates disjunctions and exercises judgement. The comments from log books are given in appendix 16 and are illustrative of the disjunctions that were constructed and the judgements they exercised as they developed their drawings.

Machining Phase 28th February to 13th June 2014

Following the submission and approval of drawings, the apprentices machine and assemble their designs. The challenges in machining are scheduling the tasks and selecting appropriate machining and fitting approaches to finish a completed assembly. Also they are not used to manual machine work and this requires some reactivation of earlier competences. The value in machining the design is twofold. It consolidates and re-activates earlier experiences in machining practice and extends the learning curve so that the learning during concept development flows into the practical activities of draughting and machining creating more opportunities for disjunction. The following is an example of the disjunctures that were constructed in this last phase.

The stock material they had acquired was generally oversized and this greatly increased predicted machining times.

One group had designed a fixture that was too large for vise work but hadn't considered the capacity of the machine bed during design.

The actual dimensions of the perimeter of the base plate are not crucial to design however all of the groups exhibited a fixatedness and worked to their drawings rather than change base plate dimensions.

There was some reliance upon material removal to create components however 2 of the groups considered and adopted the options of electric discharge machining of hard to machine profiles and welding for joining.

Group 4 purchased over centre clamps as part of their pallet locating system instead of making them.

On occasion machines broke down or tooling needs weren't anticipated when ideas changed. The difficulties that they encountered were not anticipated or identified as risks.

Having to cope with these situations provided them with opportunities to confront planning fallacies and errors. The following dialogues illustrate the nature of disjunctures that arise when the knowledge generated in the design stage is challenged by the practicalities of making the design in to a working artefact. The disjunctures arising in the practical activities provide a force to the learning experience that cannot be fully experienced in mental reflection. The undergraduate students didn't make their designs and so opportunities to confront the validity of earlier judgements were dependent upon the re-activation of memories that are imperfect and susceptible to being altered by the individual engaged in the reflection (Khaneman 2011:199 & 202).

> "After checking the material we realised we have to make alterations to our design for the fixture plate".
>
> "All of the manual millers were in use so we had no choice but to use the CNC miller".
>
> "We started to machine the locating pins but cannot finish them until we know the finished hole sizes".
>
> "Machining took longer than planned due to issues with the drawings and tooling".

> "Because of incorrect dimensioning on the fixture plate drawing we were unable to progress with machining it".
>
> "Alternative tooling should have been ordered for the cam, we didn't have a drill of the correct size due to a miscommunication".
>
> "The only problem that we have still not resolved are the whole positions on the fixture plate".
>
> "We have discovered that there is not enough material on the fixture plate to mount the cam, after discussion we thought it impractical to weld on an extension but to reduce the cam pintle diameter from 25mm to 18mm and make a bush to fit the cam to the pintle".

6.3 The Occurrence of Disjunctures in the Learning Process

In overview the projects were at broadly similar stages of development throughout. The judgement categories in each group are also similar. The problem space has 2 distinct areas of difficulty and the judgements in the conceptual stage are both heuristic and rational, the former being noticeable in planning, risk and project management and the latter in the actual design of the work holding device. After intending an initial problem space, the learners develop their plans and designs and redefine them iteratively. Because the project is divided into 3 phases this implies a logical order in the development of the design that the learners adhered to superficially. Throughout the project earlier stages were frequently revisited and revised as disjunctures occurred.

The problem space was skewed and the learners placed a premium on technical development at the expense of project control. They experienced difficulties in project planning and management and tended to avoid re-work. The groups had to be encouraged repeatedly into revising project plans alongside their log books. The learners experienced great difficulty in planning and coordinating activity and predicting the amount of time and effort required for each phase. All of the groups over ran the final deadline and did not complete the making of their designs, however the machining phase provided opportunities for disjuncture and enabled the learners to review design judgements decisively and critically by active learning.

One important consideration of design is ease and cost of manufacture. The activity of actually making a design to confront misconceptions and over-optimism could be considered to be a valuable pedagogic objective in developing professional judgements. The groups relied heavily on material removal because this is their normal environment and the availability heuristic created an inertia to seek other solutions. Underestimating the effort and time in material removal was remarkable given their machining experience. Overestimating capability and underestimating or ignoring the impacts of negative effects is a common bias in planning fallacies but I expected their heuristic judgements to be much nearer the mark, however it appears that experience alone did not improve their heuristic judgements of measurement and prediction.

Optimism is a strong driver of human action but the failure to recognise overconfidence is a serious problem in reasoning. The groups could have improved their estimates of machining time by resorting to more rigorous use of empirical formulae to generate a base line prediction of machine time. None of them did this. In the draughting and machining phases over confidence in decision making is a dominant feature. They over assessed their ability in computer aided drawing (CAD) and machining and severely underestimated the difficulty in producing representations of their ideas and the impacts of negative occurrences such as broken machines and missing tooling. Judgements of practicality about drawing standards and machining were not exercised rationally despite having analogous experiences to work from. Judgements of instrumentality were directed at trying to play down the seriousness of those judgements of practicality. In reviewing this phase I made the decision to give future groups additional tuition irrespective of whether they considered themselves to have any facility with CAD.

6.3.1 Loss and Risk Aversion in Engineering Judgement

One of the overall assessment criteria the learners were aware of was the need to maximise profits but keep overall costs to a minimum. Three of the groups resorted to purely heuristic problem space definitions to arrive at initial costings whereas one group considered using costs from similar projects as a baseline guide. The first case relies on the assumption (heuristic judgements of measurement, value and appropriateness) that the costs can be estimated reliably if the problem space composition is reasonably accurately defined. The latter on the heuristic judgement that previous projects had similar characteristics that will provide a reliable indication of costs. The first case tends to optimism even among experienced practitioners but the latter case has the advantage that estimates are likely to be less optimistic providing that the case histories are actually comparable and not merely superficially similar and that the data distribution is not ignored in subsequent judgements. In this case however they made the error in judging the complexity of other cases to be the same as their project so their initial estimate is low and optimistic.

The groups become more sceptical as the problem space develops leading to increasingly inflated estimates of costs. All of the groups were told they could obtain expert advice about their design at a cost to their project and consequently included in their estimates a sum that they were prepared to pay for such advice. As the projects approach the end of the first stage, after some period of deliberation, groups 1 and 2 submitted requests for information to confirm some aspect of their design and agreed a price that they would have deducted from their profit margin equivalent to a consultant rate for one day. Noticeably group 3 delayed sending in a request until it was too late to action before the deadline and regretted their procrastination and group 4 failed to judge the necessity to ask for assistance after realising they needed help. This scenario embedded in the project compelled the learners to examine and judge the value of necessary knowledge compared with the value they place on their own efforts and the value of the utility of purchasing in expertise. They know they will get higher marks for doing their own reasoning but they also know they will get credited for making sound judgements in time, the resulting cognitive dissonance is remarkable.

Despite the cognitive effort involved in doing the work themselves they were reluctant to reduce their profits in order to make the way easier for themselves. As soon as the effort is represented by a quantifiable amount the learners become sensitive to costs as well as losses and are immediately faced with a disjuncture. We are sensitive to potential losses to the extent that we pay more attention to them than potential gains when considering a trade off (Khaneman 2011:284,293). If the costs of over run are significant the loss aversion heuristic would enable a snap decision to buy in help. However in this complex scenario the loss aversion heuristic does not appear to be dominant. The competing objectives of reward for their own work and making a timely judgement for assistance at some cost makes the decision much more difficult, compelling the groups to actually think carefully about the balance of costs and losses.

It is as if the amount of money they would have had subtracted from their profits subconsciously represents more value than the effort with which it was arbitrarily equated.

Judgements of value become more complex when we try to assign a quantum to something that has a utility value. The learners subconsciously placed a premium on their work hence their requests were for expert opinion to confirm their thinking rather than do thinking for them and the judgement is not one of, “we need help let’s ask” but one of “we may be right but how much are we prepared to pay to confirm what we may already know?” The latter question is much harder to answer and the conflict for all of the groups was noticeable and in two of the groups the aversion to loss and the risk of wasting resources appeared paralysing. The requirement to ask learners to consider forecasts of cost and manufacturing effort in a design project adds an interesting dimension to the project. It may also have other useful effects on group work and the willingness to engage in demanding work.

Khaneman (2011:55) refers to some potentially interesting effects when money is introduced into a problem space. He cites Vohs et al (2006) Who carried out a series of studies on the effect of priming people with ideas of money and the impact upon group function, collaboration and self sufficiency. People who have an associative trigger of money (costs and losses) exhibit selfish behaviours and are less inclined to collaborate, however they also become more independent and persevere approximately twice as long on difficult problems. The reluctance to ask for assistance could be due entirely to this priming effect. Planning and costing projects in terms of materials and effort are useful learning objectives in engineering competences. The additional consequences for ALL environments is that it appears learners can be primed to engage in system 2 reasoning for extended periods simply by requiring them to cost their projects. The dysfunctional behaviours in group 4 may be partly attributable to this priming.

6.3.2 The Effect of Experience on Judgement

As previously noted the learners had little previous experience of fixture design so that constructing new knowledge and schema form a large part of the cognitive load. They all however have various experiences of work holding and machining practices from their daily work and these experiences are re-activated in their problem spaces. In several cases it can be seen that judgements of appropriateness are affected by the salience of previous experiences resulting in selections of materials, fixture configuration and work piece clamping that conflict with the requirements of the project specification. In the cost estimating case the admission of concrete new evidence relating to time, materials, labour costs etc. can be readily added to previous estimates without the need to make major adjustments to systems of belief.

Chater (2012:61) considered the effects of previous experience on actions and decisions as important to decision making and that new decisions are often made to be consistent with established systems of belief. To admit previous experiential knowledge to a problem space it must be judged to have characteristics that are in some way comparable to the state of affairs intended in the problem space. The experiences will have been heuristically judged to be similar, relevant and appropriate.

The decision to admit experiential knowledge must also have some judgement of value about the utility of the knowledge. A successful decision maker would not re-activate experiences that they believed were onerous, painful, risky or likely to prove ineffective. They must believe that the knowledge is potentially useful and so the heuristic decision to include previously learnt behaviours and knowledge states must rest upon previously successful circumstances. This view is supported by Hammerstein & Stevens (2012) who propose that successful rather than consistent decisions are favoured by natural selection. The utility of earlier successful experiences will be a heuristic judgement of counterfactuality. Re-activation of previous knowledge states also depends upon a judgement of factuality, that is, the knowledge is sufficient and saves the effort of looking further.

6.3.3 Processes and Outcomes in Problem Solving

The groups have a fixation on the project outcome and their effort is focussed on the discrete technical processes of producing an artefact. They rely on the technical processes as a conduit to 'pull' the group action as opposed to managing processes by using the project documentation and record keeping to drive group action. Judgements of practicality, appropriateness, relevance focus on performing technical engineering practices rather than the management of them. Cognitive bias affects intentionality so that worldly phenomena that are entirely stochastic appear more predictable than they really are. With hindsight, memories are re-activated that make the narrative more coherent and the idea of predictability is reinforced. Two sections of each page of the logbook require the apprentices to set out planned actions. This represents their intentionality of the problem space and their decisions. The second section requires a record of transactions and any other decisions they made in order to cope with changes to plan. The last section requires them to reflect on how well they thought their planning was. The logbook is set up in order for me to infer their judgements. When the logbooks were conceived it was my intention to include a reflective section in order to ensure that the learners improve their planning through reflecting on their successes and failures.

This strategy was partly successful. Initial log records were superficial, lacking specific or salient details and reflective reports were quite vague heuristic assessments of performance. This improved after a period of time permitting practice and some guidance using exemplars. The following selection of initial log entries reveals a predominance of confidence in prediction that ignores the very real effects of randomness and unpredictability of events (Khaneman 2011:115). Convinced in hindsight that their planning was almost flawless alternatives weren't noticed. Heuristic cognition doesn't track alternatives and the ambiguities in choices are not remembered. (Khaneman 2011:80). This suggests that learners need very specific guidance on developing skills for critical reflective practice.

Group 1:

1. All of our planning was accurate and all the team members had an input.
2. The final costing is very similar to our initial estimates.

3. All of our planned actions came out well, we had a great discussion on fixture points.

Group 2:

1. Yes the planning was correct as we have good idea of what we will be doing over the year.
2. There were no alternatives to the plan.
3. No major alterations, the plan was followed successfully.
4. The plan was followed but we came to the conclusion we had to rethink our mechanism.
5. The project is going to plan concerning the project drawings.

Group 3:

1. Planning was correct but more detail should have gone into the Gantt chart.
2. Planning was correct but calculations were not done because sizes were incorrect.
3. Last minute planning was correct as we discussed what was required and completed the presentation.

Group 4:

1. Everything went to plan as we hoped and all tasks were completed.
2. Our plan was accurate.
3. Planning wasn't correct, we tried to solve the cam forces and couldn't. We should have submitted a request for information the week before.
4. The planning wasn't good, we need to get the pins drawn and didn't get a bill of materials finished.

6.4 Case Study 2 Conclusion

6.4.1 The Technical and Socio-technical Demand of the Problem Space

Fig 4. shows a subjective plot of the problem space for this case study. Technical demands range from simpler knowledge constructs around materials selection and calculating speeds and feeds to more rigorous problems of mechanics and kinematics. Socio-technically, the demands were moderate and beyond health and safety requirements in the work environment, there are no obvious ethical, social, or regulatory conflicts that impact upon the design and manufacturing process, the majority of socio-technical disjunctures arose either in project planning and the behavioural issues such as work allocation, group work and the judgements made about presentations to client. The groups' experiences of judgement in these areas showed they experienced the greatest difficulties in organising group work load. These third year apprentices normally work in isolation and under supervision of a production manager and manufacturing engineer and do not have to make these decisions for themselves.

Working in a small group was a novel and challenging environment that made some aspects of the task more difficult but provided the opportunity to exercise many of the attributive judgements about group working. Heuristic judgements featured at all stages of the learners development of the problem space, and it is tempting to conclude that they are directed at reducing or avoiding the cognitive effort in reasoning or conflict. I propose that they actually proceeded, in the first instance inefficiently, by considering the coherence of several potential schema by which the problem space boundary eventually becomes apparent. Coherence is a term I use in the context of this thesis to represent the heuristic judgement of plausibility of the narrative of the accumulated 'evidence' as opposed to the real validity or truth of any of its content (Khaneman 2011:85,114).

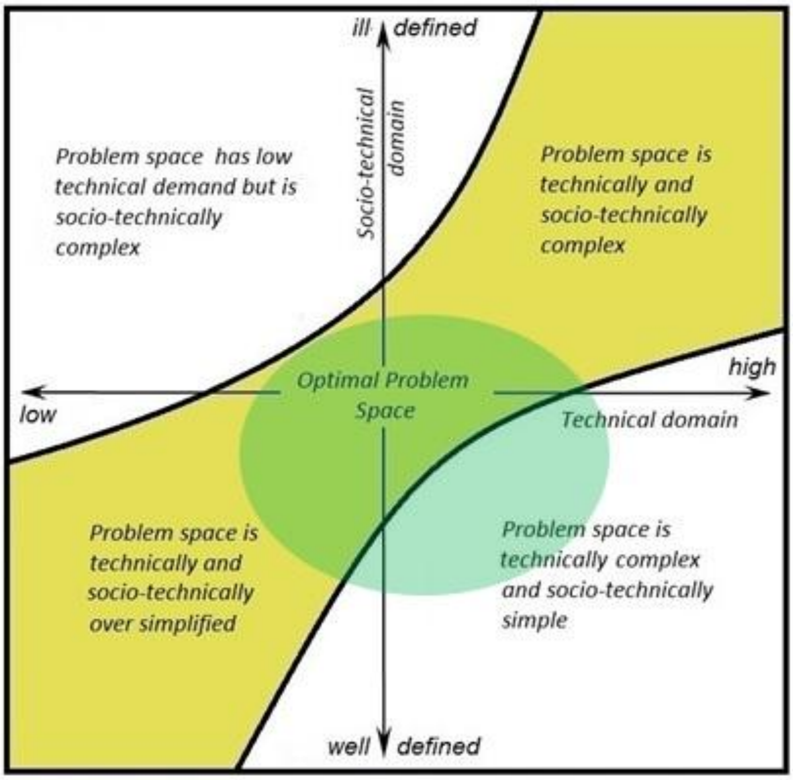

Fig 4. Apprentices' CNC Work holding Project Problem Space

Knowledge forming a problem space has two principal components, that which is known from experience (phenomena) and that which is the intentionality of the learner (noumena). The problem space is the state of affairs that they intend by judging the relationships between the knowledge states. The problem space at any one time is the culmination of a complex series of judgements that can reinforce or obliterate previous beliefs, it is not the totality of all of their experiences because previous states are forgotten in order that new beliefs can be realised and remembered. Processes are lost and forgotten in the flow of experience Romdenh-Romluc (2011:18). For this reason definition and development of a problem space is not the application of rules in which a solution emerges through a sequential and logical procession of phases. Rather the process is characterised by constant change and ebbs and flows in one direction and then another as new and re-activated information is admitted to, or discarded from the problem space.

If the progression of the groups is compared to an overall structure (the intentionality of an external observer) it appears to be poorly structured. By accepting it for what it is and without assuming it should be structured in a particular way, the problem space does not develop sequentially with the closure of a defined phase and the opening of another. The learners progress iteratively, discovering disjunctures and then by judgement of analogy, practicality and hypotheticality, intend a state of affairs that they can make a judgement of factuality that satisfies the conditions (Romdenh-Romluc 2011:17). This does not imply that they progress by advancing at each disjuncture. The next disjuncture may compel them to revisit knowledge states that they had already considered complete. Heuristic judgements are a remarkable feature of the process. Every time a disjuncture is cogitated, heuristic judgements are exercised first, sometimes with unwarranted confidence which can take lengthy dialogues and considerable cognitive effort to unpick. Social factors influence the process and function of dialogues which express intentionality, reasoning and judgement and contribute to the generation of disjunctures.

In observing the way learners define and develop problem spaces, we observe the way human cognition deals with uncertainty. Where we wish to provide a learning environment for students to learn to develop judgement capacity and cope with uncertainty and the absence of experiential knowledge, that environment must enable the discovery and satisfaction of disjuncture (Jarvis 2006:7). To tutor learners in disciplined structured formats for complex problem solving that employ sequence and rule we may be inadvertently requiring the learner to think in a way that human cognition is not evolved to do when coping with large scale ill-defined problems. From the case studies it can be seen that judgement and decision making is anything but consistent. If reasoning were to be a purely rational and logical process there may be a tendency to greater consistency in judgement. If consistency were a cognitive advantage in judgement we may see greater similarities and correlations in problem space definition right down to operational levels of detail. The learners however did exercise quite different mediating judgements, intend different problem spaces and constructed quite different solutions that in the perspective of each group is the most appropriate solution. However, Chater's position that judgements are made to be consistent with established systems of belief could explain two phenomena. Where an individual makes judgements that are anchored in prior beliefs and experiences they appear less likely to be flexible or attempt a solution that is innovative. This inertia in thinking may also be a cognitive brake on any reasoning that challenges current beliefs and appears radical and risky. There is however significant variation and according to Hammerstein & Stevens (2012:3) variance in decision making is advantaged where natural selection favours successful decisions rather than consistent ones. Given the predominance of heuristic judgement, that variance could be due to irrationality. Moreover it suggests that just making learners aware of the cognitive issues in making sound judgements may not ultimately improve their overall decision making. It may however as part of a learning programme, enable reinforcement of the need to be more sceptical of the judgements they make particularly those of hypotheticality, factuality, counterfactuality and instrumentality.

7. Case Study 3: Mechanical Design & Sustainability Assignments

7.1 Design of Linear and Rotational Kinematic Linkage

7.1.1 Introduction

The learners who participated in this case study where 2nd year students from the BEng Mechanical Engineering and BEng Automotive Engineering programmes. There were 130 students in the cohort of which 5 students were female. All of the learners participating in this case study were male. The Design and Sustainability module is comprised of 2 assignments each of one semester in duration. The projects are two design projects for mechanical, automotive and electrical engineering undergraduates at Coventry University, the full specifications are given in appendices 10 and 11. The first project duration is for the first semester of the trimester 2nd year. In this project the students have to work in teams to design a mechanism to convert a rotary input into a linear output motion and they have to comply with the following restrictions:

1. The solution must be a mechanism-based assembly.
2. The solution must not have the rotary input directly driving the linear output.
3. The solution must be assembled to a generic base plate.
4. The solution should have the human interface outside the boundary of the base plate.

The learners were provided with 2D drawings of the base plate on the Moodle page and a physical example was also made available. The specification provides a list of nine deliverables, one of which is a full report with a further six criteria. The assessment criteria and marks are also provided for the nine deliverables together with additional advice on submission procedure and presentation, quality, referencing, depth of discussion and appropriate content.

7.1.2 The Scope for Judgement in the Project Specification

There are a number of well known mechanical systems for producing the required motion including for example scotch yoke, crank and slider, cam and follower, Whitworth quick return mechanism etc. and each of those could incorporate some variation in dimensions or drive mechanism. The number of solutions is large but still bounded within a range of feasible mechanical systems. In the technical domain, the students are free to select and develop any system that they judge to be relevant and suitable to the purpose and for which they can justify their judgements. There is scope within the project problem space for exercising judgements of discrimination, composition, appropriateness, causality, factuality, hypotheticality, measurement, counterfactuality and instrumentality. Further the technical demands of the project are such that after an initial heuristic problem space definition learners should be sufficiently compelled by the demands of the project to exercise rational, system 2 thinking during the latter stages This includes a Function Analysis of the system (FAST) with kinematic and mathematical analyses, the draughting of the system design and inputting the drawing file to DelCAM to output a CNC programme. The objectives and assessment criteria are all technical and there is no explicit socio-technical dimension to the problem space other than the immediate social interaction of the team members which is not assessed.

7.1.3 Data Collection Method

8 opportunistic observations were made of the students working in teams during tutorial and extra tutorial meetings over the duration of the one semester project. Attendance from some teams at tutorials was sporadic and not all teams were disposed to invite me to their extra tutorial meetings. Subsequently, it was not possible to see all teams on the same days. The records are presented chronologically team by team.
The students' actions and dialogues were manually recorded. Four teams provided a reflective precis on request, the participants were chosen opportunistically during the tutorials. Observable activity occurred after the first 4 weeks by which time the teams had already put together several concepts for consideration. Some of the larger records of observations, dialogues are presented in appendix 17 in chronological order for each team.

7.2 Phenomenology of the Learners' Experience

1st observation of Group K,18th November 2013

This team were observed working through an exercise in tool set up using the DelCAM software. The session was led by the tutor who directed the students through the menu structure and dialogue boxes while explaining tool setting procedures. The tutor talks through many software features but there is little self directed activity from any students. Two students were entirely off task using their mobile phones, at forty five minutes the entire team was disengaged from the activity and were using mobile phones.

1st observation of Group A, 18th November 2013

All of this team are working independently of each other on the DelCAM software. The tutor talks through the features of the software and the students follow the tutor one instruction at a time. The students drift off task and talk through the session to each other on a related topic.

> "Is there another meeting Thursday?"
>
> "Yes, ... we need to do the Pugh Matrix."
>
> "We have four concepts to take forward, one has similar features to two others and one to be rejected because of its complexity, we'll make the decision on Thursday."
>
> "We have to select a particular concept and justify our choice."

The students make judgements of practicality that are directed by the criteria for requirements off assessable components rather than exercising judgements about what they intend is necessary.

2nd observation of Group A and reflective precis, 25th November 2013

Tutors have now issued a statement changing the specification to include a requirement to incorporate a tensioning mechanism and calculate forces if belted systems are used. This change of specification arises from a perception by the tutors that students are all opting to use belt systems because they think the design task will be easier. In reflective thinking, judgements can be seen that are not readily detected during the initial stages of problem space definition or even later during re-definitions. The decision to plan is one of practicality and counterfactuality. There is hindsight in the re-activation of memories when planning isn't carried out. The student responses indicate a judgment of inference and intention attribution toward the tutor by predicting the probability of an event on the basis of experiences. The bias inherent in this kind of predictive behaviour is an availability heuristic in which instances that can be recalled must be important. According to the assessment criteria there is no specific requirement for planning and no marks for it but he expects assessment on planning because he has received a tutorial on the subject so he believes it is the tutors intention to assess planning. The student justifies the change from belted system on the basis that tutors had told them not to use it. This is a judgement of instrumentality and a confabulation. In this is a heuristic, failings in one's own team are explained away as being purely circumstantial because they were presented with no option. Tutors had in fact told them that if they used belts then certain criteria must be met. There was no directive not to use belts.

1st observation of Group G,19th November 2013

The team leader reports on progress. The team have developed three concepts and are awaiting the completion of one more. They have an idea to use a belt drive to eliminate the need for gears which are thought to be more difficult to implement. The concept will be drawn up using CATIA by Thursday and they plan to use CES software for information on materials. At their next meeting they will assess their progress to date. The decision not to use gears is not a rational judgement of appropriateness but a judgement of hypotheticality involving value, discrimination and practicality. This is probably a heuristic judgement, there is no evidence to suggest they may be aware that concepts of diametral pitch of gear forms and distance between gear centres is complex. It may simply appear to be so.

2nd observation of Group G, 21st November 2013

Description of activity is given in appendix 17.

3rd observation of Group G, 26th November 2013

Description of activity is given in appendix 17.

In these observations, the learners appeared to be focussed on completing various tasks that make up the project specification. The need to provide specified proofs of development such as Functional Anaylsis Systems Techniques, free body diagrams and Pugh matrices provided a regular environment of targets within the problem space that guided the intentionality of these learners. From the observations the learners express dissociated cognitions as propositions in an unstructured way much the same as those observed in the previous case studies. The decisions are also still largely heuristic and it cannot be concluded that the adherence to these procedures increases the incidence of exertion of rational judgements by the learners.

Record of reflective precis from one of Group G, 26th November 2013

Who made the most important decision and why do you think it was important?

> "The decision by the team leader as proposed by me, to divide the team into 2 teams and sharing the workload"

Which of the decisions made by the team did you disagree with and why?

> "The idea of using a belt in our design, but after some research we decided to stay away from this because it would have been very complicated and not very sustainable."

What alternative were possible?

> "Using spur gears was one of the ideas which we used because it was the least time consuming and was the most simple design."

What effective/appropriate solutions will result from the decision?

> "The final decision to use spur gears was a good one. The reason being that they are sustainable, easier to construct and made of the same material as everything else."

In this precis, the first statement is a judgement of counterfactuality. The second statement begins with a judgement of counterfactuality followed by two heuristic judgements of discrimination reference culminating in a judgement of instrumentality. Statement three is both counterfactual and instrumental, the hindsight is qualified by two heuristic judgements one of measurement and the other of discrimination. Statement four is a restatement of the third. The respondent has introduced different *judgement of discrimination. By introducing other discriminations the respondent makes the narrative around the decision more coherent.*

7.3 Case Study 3: Design of Collapsible Engine Hoist

7.3.1 Introduction

The second assignment duration is throughout the second semester, the students working in the same teams as the last assignment, were tasked with designing an engine hoist for lifting and removing an engine and gear box from a motor vehicle engine compartment. Difficulty in maintaining communication with the groups were such that only Group K were observed in this project. The design had to meet the following criteria.

1. Easy to use and collapsible for storage when not in use.
2. The solution should be sustainable.
3. The solution must be a fabricated using standard section materials and proprietary items.
4. It must be capable of raising and clearly removing a load with an appropriate factor of safety.

7.3.2 The Scope for Judgement in the Project Specification

The mechanical systems useful in lifting applications are limited by factors including safe working load, ergonomics, kinematic considerations and size. Although there is not one optimal solution that fits the criteria, this limits the number of potential solutions and the problem space technical domain is relatively restricted. Within the technical domain, the students can freely develop any system that they judge to be relevant and suitable to the purpose and for which they can justify their judgements. From statements 1 to 4 above, they also have to satisfy particular socio-technical demands that may conflict with some technical demands and provide opportunities for disjunctures.

7.3.3 Data Collection Method

Twelve opportunistic observations were made of the students working in teams during tutorial and extra tutorial meetings over the duration of the one semester project. The students' actions and dialogues were manually recorded. The project ran from the January 2013 to March 2013. In the first week, the students received a tutorial on applying the Function Analysis System technique (FAST) followed by a brief exercise using FAST on the design of a spray bottle in preparation for their work on the engine hoist development. The observation records for this project are given in appendix 18.

7.3.4 Phenomenology of the Student Experience

1st observation of Group K, 20th January 2014

The students appear to be unfamiliar with the process of FAST diagrams. An exchange of ideas involves putting forward a number of propositions as they explore the problem space. The respondents exercise judgements intending alternative problem spaces. The interaction generates a shared experience of the problem. After 20 minutes the tutor intervenes and demonstrates an outline model FAST diagram, i.e. main function, sub function. The students then return to the problem. Students conduct an internet search on spray bottles, the learning is implicit and does not have a particular objective other than looking at types and terminology. The group discuss a range of attributes for the bottle. During this observation the students are making conjectures about the problem to construct an initial definition of the problem space. Their reasoning is focussed on the action of construct a functional analysis systems diagram of the spray bottle. After the tutor intervention the team change from discussing physical properties to consider functions. The propositions are not structured in any particular way i.e they do not deal with one part of the sprayer at a time and then the adjoining part but quickly move through attributes such as aesthetics, safety, ease of use, visibility. The FAST method focuses on structured approach by function but the intentionality of the learner's to define a problem space is still driven by the availability heuristic.

2nd observation of Group K, 11th February 2014

Description of activity is given in appendix 18.

3rd observation of Group K, 12th February 2014

Description of this activity is given in appendix 18

4th observation of Group K, 24th February 2014

Description of this activity is given in appendix 18

7.4 Case Study 3: Conclusions

7.4.1 Project 1, Linear and Rotational Kinematic Linkage

The first four weeks of the project to design a mechanical linkage system was tutor led, students were not engaged in an learning environment that could be considered activity led. These tutorial sessions were well attended but student interaction was noticeably low unless they were directed to do something by the tutor. In the early stages of activity led work, the students are required to develop a number of ideas and select one. Complying with this requirement could lead them to intend a wider initial problem space if they were to research a range of mechanisms for ideas. In practice they intended a problem space with ideas that they could re-activate from other experiences. Crank and slider configurations with either gears or belts were the concepts most commonly proposed. This is a normal availability heuristic that operates on immediate examples that come to mind when evaluating a specific topic, concept, method or decision. It makes us think that memories that are re-activated most readily are also the most important or valid.

Among the observed teams a consensus emerged that belt drives would be easier to design and implement. This appears to be a heuristic judgement of discrimination. It is not fully understood why this occurred, there was no evidence they had done any research on gear systems that would provide a rational judgement of factuality to reject the use of geared systems. It may have been they simply judged the drawing of pulleys and belts on CATIA to be easier than drawing gear forms. This 'belt simplicity' meme appeared to spread rapidly throughout the cohort. By 25th November it had come to the attention of tutors who altered the project specification in such a way that the students now perceived belted systems to be too complicated and consequently they reverted to developing designs that used gears. The reluctance of students to engage in this level of effort may be explained by avoiding the cost of cognitive effort. System 2 thinking requires mental exertions and where a coherent, though potentially weak or erroneous solution will do, system 1 takes over.

The heuristic judgement of System 1 described by Khaneman and in the methodology section was a predominant feature of the student experience of making judgements. From the project criteria it can be seen that some of the components that require the greatest cognitive effort attract quite modest marks. For example free body diagrams and appropriate engineering analysis attracts only 10% of the marks and if you get it wrong you may spend a lot of effort for only say, 3% of the marks. The detailed justification of the solution choice similarly only attracts 10%. There is no indication from the specification exactly what an appropriate engineering analysis or detailed justification actually is. If system 2 thinking is a pedagogic objective in itself the marking scheme would have to address the amount of effort involved in finding the solution. The first four weeks of the project from the 21st October 2013 to 12th November 2013, the students were given preparatory tutorials for the project in the use of CAD and DelCAM and Powermill Pro software, post processing drawing files, machining procedure and fundamental Computer Numerical Control principles.

7.4.2 Conclusions on Project 1 Reflective Precis

The reflective precis from the first project provide a particular insight into the recollection of events and so it is explored in depth in this section. In the reflective precis from team A the effects of bias during the re-activation of memories becomes evident. There are two distinct examples of the way cognitive biases affect reason from this record. In the first case the student thinks they will be assessed on planning because they had a tutorial on project planning. Human cognition is geared up to try to anticipate and predict the behaviours and expectations of others in order to cope with social interaction. This predictive thinking may be based on experience or a rehearsed 'plan of intentions'. It is unsurprising that students listen to tutorials and interpret phenomena as indications of the intentions of the tutor. The representativeness bias (clustering illusion) is very powerful, the student can be convinced of the likelihood of an event (assessment) even when there is no evidence for it (it isn't explicitly listed in assessment criteria).

The second instance occurs when the student relates an event that didn't actually happen. This is a confabulation. There is no intent to deceive, just justifying their change of plan from belt drive to gears relies on a judgement of instrumentality so that their narrative changes from repudiating an implementation that was perceived as too difficult to one in which they were told to reject it. In this way the failure to complete a design using gears is explained away as purely circumstantial. Tutors had in fact told them that if they used belts then certain criteria must be met. There was no directive not to use belts. The reflective precis from team G provides a view of an alternative problem space. Here the student's judgement of counterfactuality states that after research they judged a belt system to have been very complicated and not very sustainable. The student's concept of sustainability cannot be inferred since other than this superficial claim they made no observable judgements of reference about gears and belts in the context of sustainability. It is worth noting that compared to gears flat toothed belts are very efficient and do not require lubrication or protective enclosures (excepting safety). The student referred to other judgements of reference and discrimination that are contestable and heuristic. Without sight of detailed working and research there is no premise to consider the judgements were rational.

> "Using spur gears ……… was the least time consuming and was the most simple design."
>
> "The final decision to use spur gears was a good one. …….. they are sustainable, easier to construct and made of the same material as everything else."

In ALL, excessively complex problem spaces present the learner with patterns of information that appear to be correct deductions but in fact are incorrect. Cognitive biases are also driven by exposure. A word or idea that is repeated frequently or in association with other concepts that are seen to be true is also more likely to be thought of as true. In this instance a notion of sustainability is associated with ease of construction that follows easily from the previous ideas of being least time consuming and simple to design. These learners have constructed narratives that are in their view are coherent viz the content sounds plausible and its validity is ignored. Heuristic thinking will reinforce incorrect propositions where they are not confronted by rational system 2. A project specification that demands that they rationally justify or prove statements about material attributes, structures and concepts like sustainability and appropriately weighted in assessment will compel the learner to engage system 2 thinking and confront their misconceptions.

7.4.3 Project 2, Design of Collapsible Engine Hoist

At the beginning of the second project the students had a tutorial on FAST around the design of a spray bottle as a prelude to their actual design. They have difficulty understanding the requirements of the exercise and intend a problem space with a diverse range of concepts. After an exemplar they are able to refocus their thinking on the functions of the spray bottle. The students still introduce attributes as well as functions during the course of their discussion and so miss the purpose of the FAST method. This shows an interesting aspect to the students thinking. Various techniques in project planning and product design are taught in order that the students acquire a logic or method to their thinking during design exercises. In practice when one cogitates the design of an artefact it is difficult if not possible to think of a function of one of its components and not intend what that component is like. The appearance and properties of a potential component present themselves without effort and this can be seen from the dialogues where the students conflate function with property during the FAST exercise. When an individual has no idea what the component is like or cannot recall an experience then they can re-activate or generate an experience by examining an actual part or even looking for images in an internet search.

There is a noticeable expectation that the students adopt established practices in design method by employing tools such as Pugh matrices, F.A.S.T diagrams, competitor analyses, QFD diagrams and FME analysis. The FAST exercise with the spray bottle indicates that it can provide a learning environment that exercises of a wide range of judgements including those of composition and relevance, hypotheticality, discrimination and practicality. Pugh Matrix activities provides opportunities to exercise judgements of composition, value and reference. The way the Pugh Matrix was used in the second project had an interesting aspect. Pugh Matrices are decision making tools that could be used in any number of situations. In line with established practice the attributes were quantified by applying a numerical value that represents the severity or importance of the attribute. The students each made a judgement of value and the individual scores were aggregated. This may give the impression that decisions about indefinite concepts can be made more rational simply by giving them a numerical value that codifies their relative importance in a problem space. The procedure however, essentially replaces the extremely difficult question of comparing the ‘importance of compactability’ with the ‘importance of ease of use’, by substituting a very easy question such as which is greater 8 or 3 and being convinced that the difficult question has been answered satisfactorily and rationally. It may be that simply relisting the attributes in order of importance would achieve much the same result. The adoption of standardised procedures however that are used throughout project work produces a more regular learning environment that is more likely to enable the learner to discern patterns between judgements and their consequences.

It is a strange but perhaps useful aspect of human cognition that we are able to convincingly transport concepts across quite unrelated domains (Khaneman 2011:89). The fact remains however that these quantifications are still heuristic judgements of reference and as such cannot render the culminating judgements any more rational or the decisions any more correct, they will merely appear to be. One of the students alludes to this difficulty when he says, “It's a bit hard to gauge! sort of look at the reliability of most complex parts, how can we know this?" He is in part quite correct, it is difficult. However, the student may have learnt but fails to recall that there are statistical methods that are often used as indications of reliability and maintenance, that could be used to guide judgements. They have quantified other concepts that are equally resistant to measurement with comparative ease. This particular situation underlines the importance of resorting to data distribution to inform decisions. Judgements throughout the project are predominantly heuristic. In the initial phases of problem space definition the use of heuristic judgements to bound the problem space are usual. When the problem space was defined to the point that the students intended a proposal as feasible I would have expected to see evidence that their judgements were increasingly rational as they set about proving the viability of the design. There is no definite transition to more rational thinking and the student’s statements continue to indicate heuristic judgements (see below).

> " I suppose it's an educated guess!"
>
> "Yeah that's about it?"
>
> "OK, but chains? they're time consuming to use."
>
> "The reason ours looks so much like the others is that there are a limited number of viable solutions!"

> "I think mine's hilariously stable."
>
> "I think mine's stable but not as much as these two."
>
> "I reckon mine is quite reliable, the thing that concerns me about yours is the effort required to operate it."
>
> "I thought it would be safer and easier to use hydraulics than a screw but now the design looks like many others."

The occurrence of heuristic judgements in decision making is a normal function of human cognition and may not necessarily be a problem however, where the consequences of error are severe, heuristic judgements are risky and professional negligence could be thought to be the difference between calculating the strength of a component or just thinking that it looks strong enough. Given the predominance of this type of reasoning in the students' work indicates there is a case to develop strategies to enable them to learn to be much more sceptical of their reasoning and consider steps to correct it.

7.4.4 Comparing Both Projects

The two projects are both exercises in mechanics, there is a potential but implicit similarity in that both projects make use of linkages, though the linkages in each project could be quite distinct. Other than this observation the projects are not related. The first project may provide disjunctures that lead to judgements and new knowledge that could flow naturally into the problem space of the second project though this is not obvious. The learners do not appear to have been aware of any connection. It may be the intention of the tutors that each project should provide quite distinct experiences of design and different appreciations of mechanics. One student’s heuristic judgement of reference and value indicates a re-activation of experiences from the previous project but this does not demonstrate that the student was actually drawing on those experiences, merely comparing a sense of ease about them.

> “This is a lot easier than the last project.”

There is no record that indicates specifically why he thought it was easier than the former. Their first project was only a linkage and the latter project involves materials and structures that had to be of a particular size even if the mechanisms could be considered simpler. His statement is an intentionality of how he views the whole project that he can recall when he made the statement. He is not speaking of his perception of the intensity of his role within it, though his role determines his experiences and his narratives of them. An explicit connection between the two projects may have become evident in the leaner's perceptions but this was not observed in any of their dialogues. Dewey (1938:47) took the view that learning should flow from one experience into the next and that good learning experiences should be organised to permit this to happen. I am of the opinion that this is a reasonable view and in learning environments where this is true it is reasonable to conclude that it becomes easier for the learner to intend successive problem spaces of new projects by re-activating the learning from earlier disjunctures. However, changing Intentionality of problem space is a heuristic and heuristic judgements become reliable where the environment in which they are exercised is sufficiently regular for the learner to acquire experiences where the outcomes are more or less predictable. (Khaneman 2011:239,240)

7.4.5 Technical and Socio-technical Demands of the Problem Space

Both of the project problem spaces are plotted on Fig 5. the first project specification presents a degree of technical complexity from the selection of suitable mechanisms and materials and explanations of relevant mechanical and kinematic issues. There are a limited number of mechanisms suitable for the task so that the problem space is limited by known feasible systems that the learners have to discover. There may be numerous subtle variations. There are no socio-technical demands in the problem space other than those arising from team work, communication and similar skills. For example the objective of the mechanism is a simple transfer of motion. If the project specification for example had specified the need for the mechanism to function in a device to hold something to free someone's hands to do some other function then the socio-technical domain opens up considerably. The problem space changes from one of mechanical feasibility to also incorporate utility and the tensions between these would create much more purposeful disjunctures. The second project has a larger technical demand. Mechanisms may incorporate other power systems and the design has to incorporate safe working loads safety devices and be correctly sized to perform the prescribed lifting operation. The students were able to perform an initial problem space reduction by resorting to a trade study of comparable hoists. The project also had a good socio-technical demand in that the design had to accommodate certain ergonomic and human elements and the socio-technical determinism of design for a specific market and budget.

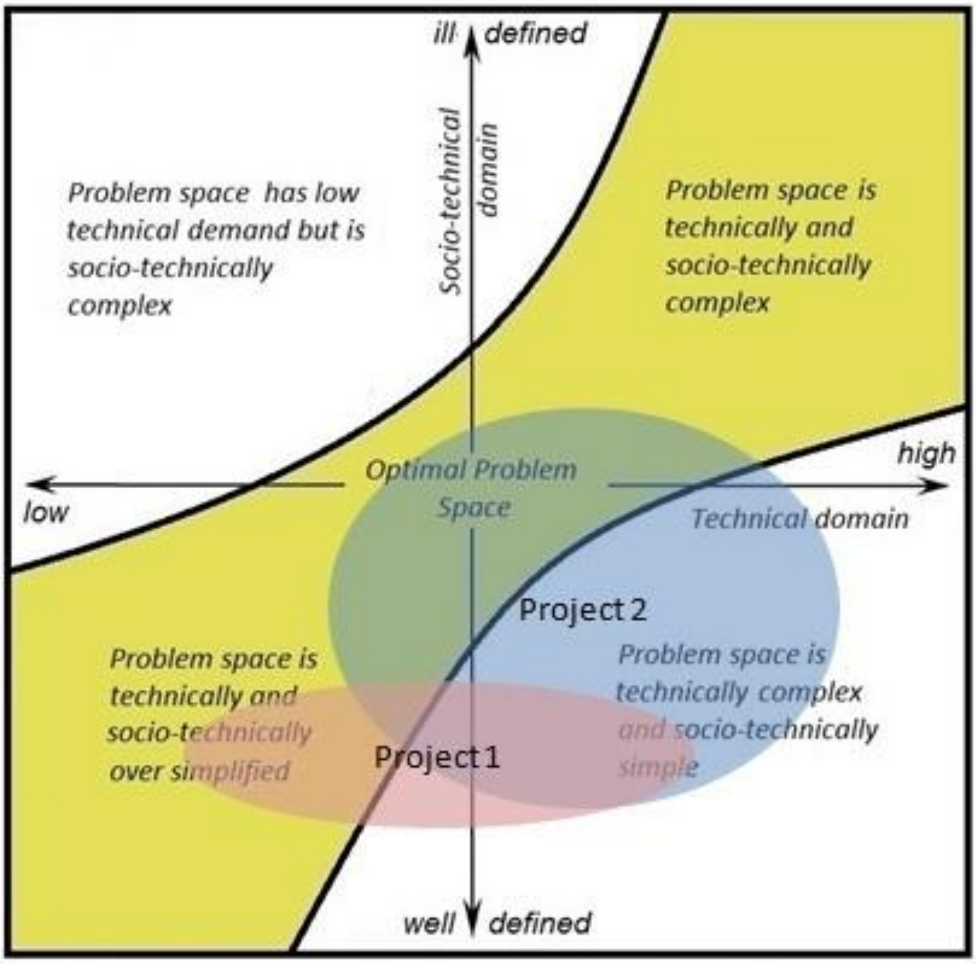

Fig 5. Mechanical Design & Sustainability Problem Space

The greater potential complexity of having a socio-technical demand can be seen from records of the learner's work and their activities such as the Pugh Matrix development. However there is no evidence to suggest that the problem space they intended was perceived by them as difficult or that its complexities presented conflicts that required any great exertion in exercising judgement. The evidence suggests that the socio-technical demand and in some cases the technical demand also was dealt with quickly by a series of heuristic system 1 judgements so that cognitive effort was minimised. There is some merit in this in as much as socio-technical issues are resistant to measurement and attempts to rationalise or quantify them require judgements of value and comparison that in themselves are not entirely rational. On the other hand such a problem space can be made more rationally bounded by a careful examination of a reference class for the product that is being designed and there is some merit in teaching learners to be aware of the problems of base rate neglect and to look carefully at reference class attributes and statistics to inform judgements.

The systems approach set out in either of the project specifications does not appear to compel or enable a linear approach to solving the problem. Nor does it seem the heuristic judgements exercised by the learners permits a decomposition of the problem in an orderly fashion. They intend an initial problem space and then re-define the problem space every time they introduce another proposition. This non-linearity in problem solving appears, prima facie, to be inefficient but it may not be. It may be that while this approach appears unguided and variable, the apparent inefficiencies may be offset by the effortlessness of heuristic judgement cognitive mechanisms. While this may lead to errors, providing the stakes are not high then the gains will outweigh the risks. In this event, improvement in judgement may be seen to be the recognition when errors and the consequences of error become significant and the need to make any decisions more robust by resorting to evidence and proof.

8. Case Study 4: Built Environment Design Integrated Project

8.1 Introduction

In this project, 3rd year students of the Department of Civil Engineering, Architecture and Building have the task of developing a proposal and design for the refurbishment and extension of the John Laing Building which houses these subject areas at Coventry University. The student project teams are drawn from across the department and each group must have architects, architectural technicians, structural engineers and building services engineers among its members. There were 253 students overall of which 23 were female. A group, typically between five and eight members, may be comprised of both part time and full time students. The mix appeared to be opportunistic in that some groups were all full time, some all part time and some with both part and full time students. The part time students work in the civil engineering and building industries and are often sponsored by employers. The project specification aims to fully integrate all the skills and functions of the different group members to solve a realistic civil engineering problem. The groups have access to computer facilities and dedicated industry standard software such as AutoCAD Revit and Solibri. The project is divided into 5 stages which are summarised from the project specification herewith. The full project specification transcript is given in appendix 13.

8.1.1 The Scope for Judgement in the Project Specification

The project is essentially open in as much as the students can modify and extend the building in any number of ways. The problem space is confined by the necessity to preserve and modify an existing structure and also a listed structure of architectural and archaeological interest in immediate proximity to the current structure. The Crossman building housing another faculty is also close by and limits the possibility of extending at the other end. The problem space endpoint is bounded by the intentionality and capability of the team and not specified by the project brief. The project specification is prescriptive and sets down very specific requirements around the content and format of assessable material. The potential technical and socio-technical demand of the problem space is very large and there are a number of conflicting areas that will generate disjunctures and the compulsion to exercise judgements. Architects exercise judgements about the utility, aesthetics, sustainability and regulatory issues of the building. These socio-technical aspects within the architects vision could take any number of forms depending upon the intentionality of the architect and in consequence impose complex and challenging technical demands on the problem space for the structural engineers and building services engineers. Engineers have to exercise judgements on how or whether they can meet the architects' designs with sound and sustainable structures.

8.1.2 Data collection method

The students recruited for this study were part of a large cohort of 262 students. I was a non-participant observer in the data collection. Tutorial sessions were located in several rooms in two different buildings and recruitment was entirely opportunistic. Three groups agreed to participate in the study. Each tutorial room was crowded and data collection was extremely difficult. On numerous occasions dialogue was unintelligible due to the level of background noise. The data collection began with three groups but ultimately it became necessary and more conducive to good research to focus attention on one particular group that had extricated itself from the environment to work in quieter surroundings rather than continue to try to capture sparse data in a very noisy environment. The majority of data was recorded by direct observation of group and individual activity with a small number of interviews. Twenty nine opportunistic observations and records of the students' activities and dialogues were made over the duration of the project from October 2013 to May 2014. The records given in appendix 19 are presented in chronological order per group. My analysis is italicised and interleaved so that the inferred judgement can be related directly to the events in question. Selected quotes of conversations are given to provide actual examples of activities and dialogues that occurred during the observations.

8.2 Phenomenology of the Learners' Experience.

Beginning 28th October 2013 the learners received guidance in the form of a lecture on the structure of the project and the expected content. Surveying, places and spaces, building structure and finishes and the final report layout is up to each team but is expected to contain, drawings, photographs and have a cohesive outline. The pretender costing must be made explicitly clear and the students were directed to look at value engineering and be able to justify their processes.

1st observation of Group E2, 28th October 2013.

There are 9 groups assembled in the tutorial room. The background noise from the groups engaged in initial discussions is very loud, making it difficult to hear the dialogue of the teams being observed. The students have a map of the John Laing building and immediate area and are also displaying on a laptop a 3D partition drawing of the ground and first floor in which the double height of the laboratories is visible. There is a brief discussion on making future decisions by discipline so that architects will decide design issues and the engineers will determine structural matters. There are judgements of practicality and intention attribution in the decision to set boundaries of responsibility. This action would be redundant if there was no attribution of an intention to cross into each other's areas of responsibility.

2nd observation of Group E2, 4th November 2013

Description of this activity is given in appendix 19.

The team discuss their proposal for the extension to the John Laing Building. They note they need 2 designs and to date they have only one proposed design. The project is in its second week. What is noticeable from the dialogue is the students are making propositions that they are also qualifying by reasons of practicality or hypotheticality. They are probably drawing on analogies or experiences and this indicates a degree of confidence in their judgements. What is also noticeable is the intentionality and availability heuristic in each individual's propositions. Each member pitches in with proposals about different parts of the building that readily come to mind rather than considering the building one section at a time. It illustrates the values that individuals bring to a problem space which make human decision making rich and unpredictable. The risk in this approach is the possibility of missing something and having to revisit and correct for the omission later.

1st observation of Group H24, 28th October 2013.

The students have a large drawing laid out on the table and are discussing the possibilities and different uses of the current space of the building. The expressions are wishful propositions phrased as “I like the idea of -….. They think that keeping the lecture theatre near the building entrance will reduce traffic through the building, they also decide that the offices in front of GL20 should be removed to improve flow. They are certain the roof cannot be modified at all. Referring to a CAD drawing hard copy they notice the positioning of the existing structural columns but cannot decide whether they have to work around them or whether they can be repositioned. They decide to re-convene on Wednesday night for the benefit of the part time students in the team. The learners in this group have intended an initial problem space and have begun to express views on the propositions that present from it. There is no conviction, just heuristic judgements of value, reference and composition. This initial and informal process allows them to share intentionality about the developing problem space.

2nd observation of Group H24, 4th November 2013

Description of this activity is given in appendix 19.

This group are now using CAD software checking the drawing scale and paper space. They are also in the initial stages of problem space definition. The team dynamic is different. What is noticeable about this group compared to the previous group is almost a complete lack of justification for their propositions. There are similar judgements of hypotheticality, practicality and appropriateness and the same heuristic approach as the other team is discernible.

3rd observation of Group H24, 25th November 2013

Description of this activity is given in appendix 19.

In the last two observations the initial problem space definition has concluded and there is an increasing rationality to their judgements as they considered structural and regulatory issues in more detail. Propositions were judged critically against rational arguments in which the majority of judgements were of practicality, hypotheticality and measurement.

4th observation of Group H24 24th February 2014

Description of this activity is given in appendix 19.

This group are near the submission of end stage 4 having corrected formative feedback on their work. Two of the team confirmed that the feedback corrections fit their expectations of omissions or areas in which they thought corrections would occur. Judgements of counterfactuality. There is a normal tendency to reconstruct memories after the fact according to currently known facts and one's current beliefs. In this way, the individuals making the judgement, construct a past that is more consistent with the present and appearing to be more predictable than it actually was.

1st observation of Group N, 12th November 2013

Description of this activity is given in appendix 19.

There are some judgements of discrimination and practicality and complex judgements of hypotheticality, relevance, composition and factuality. There is also an intention attribution about tutor expectations. Team N's discussion during this observation is around issues of sustainability that flow seamlessly into considerations sustainability of the structure. The finish is considered and there are a number of heuristic judgements of discrimination and value. These heuristic judgements ideally could have been ameliorated by referring to cases or data. Later, when they view a plastic clad building from the 1970's they are swayed from the idea of cladding with tiles by the poor condition of the aged surface. This was a heuristic judgement of appropriateness that ignores external factors that may have contributed to the state of the building.
Even in this environment where the learner brings previous experiences to a discussion with rational potential the intentionality is still affected to some extent by heuristic judgements.

2nd observation of Group N, 13th November 2013

Description of this activity is given in appendix 19.

3rd observation of Group N, 18th November 2013

Description of this activity is given in appendix 19.

The initial focus of discussion in this meeting is costing and quantities. Firstly they considered furniture and the lecture theatre and toilets. They then move on to look at materials which includes structural steel, concrete, timber, plastic boards, and glass. The discussion then moved to building services and ventilation from the floor. The positioning of stairs for circulation and fire prevention crops up again.

4th observation of Group N, 27th November 2013

Description of this activity is given in appendix 19.

The team have been missing one member for 6 weeks and they are discussing the potential impact. They agreed it has little effect on the current stage but that individual is the person with most REVIT capability and they are aware that it will impact stage 3 severely if he doesn't re-engage. In this short discussion the most prominent judgements were of counterfactuality, measurement and causality and a judgement of hypotheticality.

5th observation of Group N, 20th January 2014

Description of this activity is given in appendix 19.

6th observation of Group N 20th January 2014

Description of activity is given in appendix 19.

8.2.1 Semi-structured Interviews.

Four semi-structured interviews were recorded with two volunteers. The first interview was with a volunteer from team N on the 10th February 2014. The interviewee had taken responsibility for the BIM coordination of his team project.
The second interview was taken with same volunteer from team N on the 14th May 2014. The third semi-structured interview was with a volunteer from team H24 on the 22nd January 2014. This interviewee had also taken responsibility for the BIM coordination of their team. The student was quite despondent, in his view the project was not going that well and he's unhappy with the effort of some in the team. He talked at length with virtually no prompting. The fourth and last interview was with the same volunteer from team H24 on the 22nd January 2014. The full transcripts are given in appendix 20, my questions are italicised and the respondents dialogue is indented.

8.3 Learners' Recollection of the Learning Experience

8.3.1 Perception of Conflict

A number of important issues can be discerned from the semi structured interviews. References to technical detail or a design solution that they thought was especially elegant are noticeably absent in recollections of their own team work. The interviewees' re-activation of memories have a remarkable socio-technical focus. Particularly noticeable is that both interviewees recount the conflict between creative aspiration in design and the difficulty of coping with the consequent technical demands that it generates.

> "The Architect wanted a lot of cladding or to include something that would give a unique 'brand' image like a roof garden, and a sloping roof but that drives up structural loads and costs"
> "A couple, the structural engineers coping with complex structures wanted a minimalistic structure. The architect however wanted more architecturally pleasing designs and was annoyed on two occasions by the limitations imposed by the engineers. More time was needed for extravagant designs."
>
> "Basically the structural engineers were very much opposed to dealing with complex geometry so the compromise tended to structural simplicity."
>
> "The architect was very resistant and would have taken a strong counter argument to change."

The recollections are almost entirely couched in terms of human interaction rather than in terms describing the value, appropriateness or hypotheticality of particular propositions and the counter arguments. It is as if the details of concepts that were central to the conflict are lost in the attribution of intentions of the participants that made the judgements. According to Romdenh-Romluc (2011:18) consciousness forgets phenomena in order to construct outcomes that become the focus of the perceiver.

8.3.2 Perception of Contribution and Team Effort

Elsewhere the interviewees recollections of team actions are biased toward the negative aspects of team behaviours, instances where very positive views are expressed are rare. Again what is noticeable is that the characteristic most likely to be reported is the perception of low effort or collaboration. There are no instances of an interviewee expressing the idea that a team member had made bad decisions or behaved incompetently.

> "The Architectural Technician was ill and the Architect, assisted by one other has had to stand in for them. This resulted in a lot more discussion, management difficulties and clashes in understanding."
>
> "In stage 4 it will be interesting to see if the collaboration continues. 3 ~ 4 will, the cross disciplinary nature of the project will enable less clashes."
>
> "Some do additional work, I haven't done as much but spent time organising the team. I feel I had to prompt some of them."
>
> “The team was driven by strong personalities.”

The tenor of the responses is more sombre from the interviewee from team H24 who perceived the team effort as quite poor.

> "Had to spoon feed a lot of them and I had to chase a lot of people for BIM coordination. Some did very little and then thought the peer assessment was harsh, I thought it was realistic."

The extent to which hindsight bias pervades these judgements of counterfactuality is rather too difficult to assess without being able to test the interview responses against teamwork observations. This is possible to some extent with group N from which most observations were taken. The points of view expressed by the interviewee from group N were reasonably objective, for example he admitted that he'd done less work and then made a judgement of instrumentality about his organisational effort to justify his position. The interviewee from group H24 on the other hand felt that his contribution was significant while that of the others was not up to scratch. He was frustrated by the near constant effort of chasing team members for their input but that does not take into account the effort they actually put in which is not visible to him. There is a degree of bias in his position.

8.3.3 Perception of Validity of the Project Assessment

A feature of the interviews in this project that was not evident among other case studies was that the students readily expressed views on whether they thought the assessment was reasonable. Those issues are dealt with in more detail in this section. The interviewees both had recollections that some of the content asked for in the project specification wasn't actually assessed or that its inclusion in the assessable content was unnecessary.

> "It didn't feel that they'd looked at the Project Execution Plan, they kept asking for it but didn't look at it."
>
> "Jumping through hoops, some stuff was not needed and not marked."
>
> "1 or 2 thought we were having to jump through hoops, we couldn't use much of the building service engineers expertise."

Both respondents considered the project credit to be under rated and that this may have affected the perceptions of the participants about how much effort needed to be invested. It is something that needs careful consideration. The drivers of human action in industry are different to those that learners intend in undergraduate projects where learners have the additional goal of considering the value of an outcome not only in terms of how satisfying it is as an achievement but also how many credits they attract for various parts of the project. The effort that learners invest could be skewed where they view the credit ratings as unfair.

> "The weighting of the assessments mean that students put more effort into high credit modules."
>
> "It was a 20 credit module and it should have been higher, I'd have been satisfied if it was around 30."
>
> "I didn't like the project, there was too much to do for few credits. It wasn't a refurbishment project."
>
> "There's a timing tension with submission deadlines similar to real life balance and organisation of time. A lot of people focus on marks."

The following response is interesting. Assuming it is true it suggests a deliberate strategy to 'engineer' the social interaction of the project. Given that cognitive biases are frequent in human cognitions like intention attribution, conflicts are probably inevitable and seeking resolution is an important skill in collaboration that needs to be exercised.

> "Speaking to 'A Tutor' they try to plan to avoid issues. Some people are timid and try to avoid conflicts."

This response is indicative of precisely this point. The student alludes to the tension that is inevitable when individuals exercise judgements in situations where their values and purposes are different.

> "Nothing really bad, the criteria are a bit cloudy but it's really good for conflict resolution. The structural engineers are logical but the architects less so."

Finally a statement from group H24's respondent. He wasn't too impressed with the project or his team and was surprised with their result. On the basis of this expression, the result must have been much better than he could have predicted.

> "I've a feeling that the tutor didn't like out design."
>
> "We had a very good result, I was overwhelmed."

8.4 Case Study 4 Conclusions

8.4.1 The Technical and Socio-technical Demand of the Problem Space

The interviewee from group H24 that completed a successful project, (interview 22nd January 2014) reported an estimated 500 errors, claimed to be due to inexperience with software. This is not an inconsequential error rate that may have been higher for less successful teams and it may be concluded that the technical demands of this project are considerable though many of the difficulties are ameliorated with the support from dedicated software. From the observation records it can also be seen that the intended problem space consists of many socio-technical cogitations that relate to aesthetics, environmental sustainability and especially public utility such as traffic, the placement of rooms, corridors, partitions and access points. Making a subjective plot of the demands on Fig 6. below shows the problem space for this project. It has some aspects that are relatively well defined. There are limitations imposed by the renovation and extension and the proximity of a listed building.

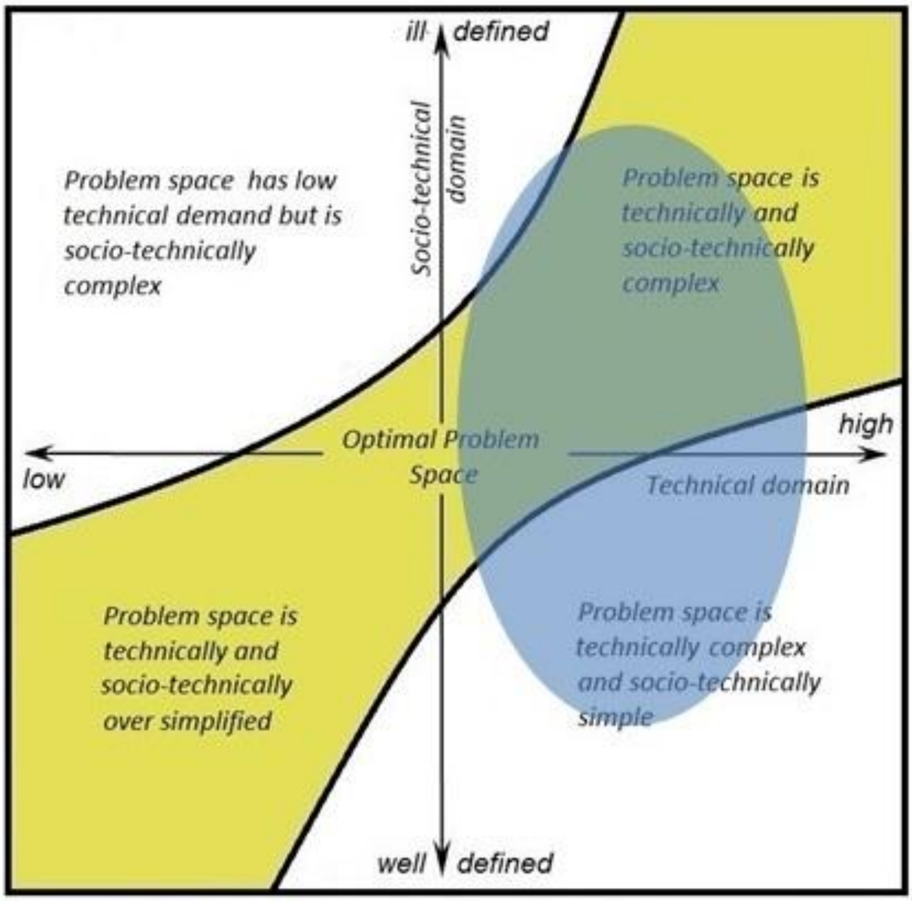

Fig 6. Civil Engineering Design Integrated Projects Problem Space

The project specification is quite prescriptive with regards to some presentational content and format on the other hand the socio-technical domain is tending to such complexity as to present the learners with a wicked environment where problems are potentially interminable and best fit solutions have to be considered by compromise. A large number of solutions is possible and many of the socio-technical issues are difficult to measure and require the exertion of complex judgements. The structural engineering students reduced the technical demand by restricting the complexity of the problem space to manageable proportions at the high end while the technical demand in other ways may be considered moderate in that the use of dedicated software reduces much of the need for difficult calculations. Error detection of the drawings is almost entirely automated by the software but relies on learner interpretation and skill to implement corrections. The project overall provides a rich environment for the learners to exercise judgements over a wide range.

The problem space has the potential for the exertion of complex judgements due to the tensions between the technical and socio-technical demand. In the extremes of this region the problem space may be too complex for learners to reduce to manageable proportions easily without losing important detail. Moreover the irregularity of the environment makes the exertion of judgement less certain and learners could become unaware of the errors in reasoning. In the exchange below a counterfactual judgement is made about an error. The error itself indicates how easy it is to lose sight of significant detail in a complex environment.

> "The floor slab is lower than the support columns."
> "We should have sorted this before now, the structural engineers and architect could have seen this."

The problem space does however, also cross into the optimal region where potential solutions are sufficiently regular for learners to discern the effects or patterns between the judgements they make and the intended solution. The statements below are indicative. In these cases the regularity of the environment can lead to the development of heuristic judgements that tend to greater accuracy because the environment provides opportunities to practice and is regular enough to be appear predictable. (Kahneman 2011:240)

> "Why's the roof sloping that way?"
>
> "I didn't want it to look like a box, also the south face slopes away for shade and solar gain."
>
> "How big has the concrete lab got to be?"
>
> " About 100 metres square."
>
> "If this becomes the concrete lab then this whole area becomes free, is that OK?"
>
> "What is it for?"
>
> "The plant room.........put storage in the ends move the cleaner's cupboard and student work room, storage and work room."

8.4.2 The Occurrence of Disjunctures in the Learning Process

The students bring several years of undergraduate learning to the project and are well versed in making judgements of discrimination and practicality in their own roles. This is evident in their knowledge of regulatory matters, structurally technical matters and the method in their approaches to the problem. When the students make propositions about how they intend the project to develop, judgements of hypotheticality are common in the problem space and subsequently when considering the regulatory issues, judgements of practicality cause them to re-examine the problem space. Disjunctures occur when the students' intentionality through the exertion of hypothetical judgements is confronted by the re-activation knowledge about regulation and judgements of practicality. The following statements exemplify the condition of disjuncture:

> "We could make the lifts accessible from both sides,"
> "There may be conflict with fire regulations and distances from fire exits."

and also,

> "I have an issue with these stairs."
> "They have to be enclosed for fire protection, basically they just need fire doors."

In the above examples the knowledge flow is interrupted by the need to reconsider whether the proposals are not in breach of any building regulations. Knowledge of regulation isn't acquired within the project but the knowledge about when to exercise judgements about working within a regulated environment is. In other cases disjunctures may result when counterfactual judgements about a proposal involve technical issues that may prove to be impediments. For example some propositions generate the need to recognise the insufficiency of knowledge in the current problem space to avoid regulatory breaches.

> "The lift shafts aren't structural, it depends on us." Observation by structural engineer.
> "OK then let's have them structural."
> "Can you work out a loading for the foundation pad and the size of the foundation slab for costing?"

and also,

> “Just move the stair so that I can visualise the whole thing. If we didn’t need those columns there what to do with this open space?”
> “If we move the columns to the edge we load the existing foundations which we don’t have calculations for!”

Other disjunctures are generated when propositions compete and the students make judgements of value and appropriateness to resolve the conflict.

> “To keep the character of the building we have to extend it lengthwise.”
>
> “Extend the lecture theatre for access from the other end.”
>
> “It makes much more sense to go into the staff car park and double the height of the foyer space.”

and also,

> "Just put another row of columns here."
>
> "Won't that totally screw up everything? - Move these?"
>
> (Architect) "No! They will wind up in the middle of the lecture theatre. The columns fine it's just the wall."

Some conflict was resolved by the force of individual's personalities rather than rationale as in the following extract from semi structured interview team N, 14th May 2014.

> “A couple, the structural engineers coping with complex structures wanted a minimalistic structure. The architect however wanted more architecturally pleasing designs and was annoyed on two occasions by the limitations imposed by the engineers. More time was needed for extravagant designs.”

In the above example the need to have proofs of structural integrity drive the engineers to press the architect to scale down their ambitions.

8.4.3 The Effect of Project Specification on Learner Intentionality

The students also intended a problem space that is impacted by the expectations of the tutorial team and have to make judgements about how to satisfy those requirements. A regular topic of conversation among teams working on a problem is the need to find out what has to be submitted for assessment. Throughout the project specification in each stage, there are repeated emphases on the need for the team members to collaborate and communicate effectively, particularly with regard to the BIM processes. The project documentation sets out in noticeable detail, the way in which the work should be developed and presented, the content of the presentation the criteria by which the project is assessed. It may be considered that the tutors are establishing a 'level playing field' in terms of what teams have to provide for assessment. Furthermore it may also be the case that the tutors are projecting what in their view is a received wisdom or good practice about the submission of construction tenders. This may be thought of as an efficient and correct paradigm where the objective is to impart a body of knowledge, however problem based learning is variable and may have other objectives or even goal free outcomes that could be thought of as part of a learning process. (Jonassen & Hung 2008:22) and as we have seen earlier, other authors have raised objections about using problem based learning for knowledge acquisition (Kirschner, Sweller & Clark (2006:75&76). Definition of the content and format of a presentation to a client is however an important aspect of a real world problem space and could be thought to be as much a part of the development of professional judgement capacity as an ability to solve the intrinsic detail of the problem itself. The learners could have been provided with more flexible or less prescriptive guidance and permitted to develop that part of the scenario as a learning outcome in professional development. The way the learners developed the problem space and the solution are much more deliberate and than other projects that were surveyed and proceeds through a number of stages in a particular order. This may be a function of having a project with defined stages and deadlines rather than a conscious decision by the students to develop the problem space in a particular way. One way of looking at this is to consider that the students are learning a particular paradigm in a 'community of practice' reminiscent of those that will be encountered in professional practice and as such may be thought of as good preparation for employment. To take an example, the emphasis on Building Information Management could be viewed as promoting an opportunity to prepare learners for future professional practice. The students' intentionality however, based on their work experiences do not see the extent to which it pervades the project as particularly redolent of its perceived importance in current practice.

9. Discussion

9.1 Review of the Study

9.1.1 Introduction

In this chapter the findings and conclusions from each of the 4 case studies are discussed. Each case study has aspects that are specific to the particular ALL intervention that was employed. Beginning with an overview of the analytical procedure the way the different contexts in those environments affected the intentionality of the learners and the judgements they made is examined. Of particular importance are the findings that heuristic judgements dominated the learners' reasoning even in problem spaces that were technically dominant. Many of these heuristic judgements were mediating and occur during problem space definition when learners expressed propositions about the nature of the problem. Significant judgements that defined problem spaces and enabled the realisation of new purposes and knowledge arose from the phenomenon of disjuncture. When the learner discovered unusual, new or conflicting information the flow of thought was halted and a disjuncture is created that challenged the intentionality of the learner. The disjuncture is resolved when the learner makes a judgement about the state of affairs presented in the disjuncture in order for the learner to proceed.

The literature review discussed existing models of learning, the nature of judgement and human cognition and the development of professional competences and judgement capacity. Within Coventry University's current definition Activity Led Learning can be expressed through different learning experiences providing that activity is put before knowledge so that the learner constructs knowledge and the organisation of knowledge and purposes. This study researched the learners' experience of making judgements through project based learning in formal and semi-formal education as forms of Activity Led Learning.

9.1.2 Theoretical Background

The theoretical approach was informed through the literature review which examined the theoretical perspectives of professional conduct and competence, pedagogic theory, engineering education, ALL as problem and project based learning, human cognition and the psychology of decision making. The ontological and epistemological basis for the theoretical framework was informed from the philosophies of Immanuel Kant, Edmund Husserl and Maurice Merleau-Ponty. A phenomenological methodology and qualitative method were selected in the collection and analysis of the data.

9.1.3 Data Collection

Several methods were employed in the collection of data. Interviews are often used in phenomenological studies however in understanding the learner experience of exercising judgement, interviews alone could not provide an unobstructed view of the learner experience. The effects of confabulation and hindsight bias in learners' reports of their experiences resulted in narratives that were difficult to distinguish from true perceptions of experience. Manual recording of observed learner activities and dialogues were used extensively throughout the study together with selected video recordings. This enabled the capture of events, and actions at the moment they occur as the 'residues' of judgement. Recording and manual records of observations were in keeping with phenomenological methodology.

9.1.4 Analysis of Findings

For the purposes of analysis, judgements had to be inferred from the learner experiences that were observable. Two distinct hypotheses posited by Lipman and Khaneman were employed in one method in order that judgements could be categorised both by attribute and rationality. In practice, this proved to be more difficult than was anticipated. Judgements can be determined from actions and decisions though in some instances judgements were difficult to infer. From the case studies it can be seen that although there was no definite action or decision in some instances, learners make propositions or proffer opinions about the ideas they think may be relevant to the inquiry. These propositional attitudes may be considered to be judgements of composition and appropriateness about the whole problem space. The learner makes an initial conjecture about their ideas in order to present them, the judgement is exercised in uncertainty and in the absence of complete knowledge, and judgements that precede propositions are resistant to easy categorisation. The complexity of judgement is also dependent upon context and many judgements are mediated or ameliorated by combinations of other judgements all of which can be shaded by systems of belief. Judgements in any category may be either heuristic or rational which adds another dimension to the complex nature of cognitions. If we take a specific example of the judgement of causality two types of instance may be encountered one which can be rational and another heuristic. The rational judgement of causality that is culminating of other mediating judgements that have rational connections and analogies may be considered rational. The learners in the first year aerospace air crash investigation study were trying to develop such a schemata. Causality however, is also considered to be a heuristic attribution. Rips (2011:77) cites Michotte's work on the perception of causality. In this case there is no rational schemata but cause is due to perception and causality is attributed to two events that are perceived to be connected. The event does not have to be actually witnessed in real time as a phenomenon, the 'perception' may be noumenal, a dissociated cognition where the chain of events is imaginary. Some of the aerospace students imagined a series of events such as an evasive manoeuvre and a collision with a flock of geese and perceived causality from these.

9.2 Apprenticeship and Undergraduate ALL Environments

The undergraduate and apprenticeship ALL environments both provided learning experiences that enable opportunities for engaging disjunctures in the flow of information. By presenting challenges that are compelling for the learner they are urged to solve them. The problem spaces are not purposefully contrived to create opportunities for disjuncture but as examples of good industrial practice in which the necessity to make good judgements is implicit in reaching a solution. This was achieved by presenting a problem of sufficient length and complexity that the solutions were not immediately obvious but need to be thought about carefully. The apprentice and undergraduate ALL environments however were essentially different in their presentation to the learner. The undergraduate environment in terms of assessable content and the presentation of that content can be thought of as more explicitly defined. Whereas the apprentices were not told specifically what they should provide in the way of assessable material but to judge and include what they thought was germane to the task. This notion sounds controversial, when objectives and formats are specified there is a sense of equanimity about the processes of assessment. However if we are to say that ALL takes place in a real or real world simulation then the presentation of detailed assessment criteria raises some difficulty. It is doubtful that any client ever provided a marking scheme for a supplier or specified the content of a sales pitch or evaluation, it is up to the provider to decide what they should include when they sell the idea of a design to a client. This is a fundamental learning curve in real world business and a real world 'wicked' skill. Wicked skills involve coping with uncertainty, irregularity and lack of information and are increasingly thought to be essential components of an engineer's education. The importance of developing wicked skills that are valued by employers in undergraduate engineers is discussed in 2.4.1. In this sense the apprentices had to make those decisions and cope with the uncertainty. They were presented with the opportunity to think about these issues and were marked on their decisions. In the event that they were unable to synthesize this knowledge there is the possibility of coaching them implicitly by question and dialogue. Consider the following specifications to the learner:

a) Your presentation should include, CAD drawings, FAST analysis and free body diagram etc.

or,

b) Present your design as if to the client including whatever information you judge to be relevant for that purpose.

They can both provide useful and interesting presentations of learning and assessable material but one of these options provides the opportunities for exercising judgements in professional contexts and the other is quite limited in this regard. From the case studies there are examples of learners exercising judgements from the analogies of previous experience and even by imitation. In case study 3 for example learners intend their problem space by adapting ideas from competitor studies and examples from groups of previous years.
The practice of specifying very explicitly what will be assessed seems counter intuitive if the intention of learning is to develop and exercise professional judgement in a real world context.

The degree to which project specifications are prescribed varies noticeably across the undergraduate projects. Comparing the apprenticeship and undergraduate situations, the undergraduate cohorts are approximately an order of magnitude larger and have significant numbers of learners who have English as a second language and differing educational backgrounds. It is potentially though not necessarily more difficult to coach learners implicitly by dialogue in larger groups where there may be communication difficulties. Providing additional support by providing more prescriptive specifications may be seen as a way to mitigate those difficulties.

Both the undergraduate and apprentice learners experiences involved design and computer aided drawing. These activities provide a rich environment for exercising a range of judgements through formal and informal mechanisms. The apprentices' ALL experience additionally had a significant practical component that followed on from the design stage so that judgements that were exercised in design had to be re-activated and confronted when they attempted to make their designs. During the practical activities of machining and assembly the learners often find they have created manufacturing difficulties in the way that the design was envisaged. The validity of earlier judgements of practicality and hypotheticality about design are brought forcibly and vividly to the attention of the learner creating further disjunctures. Some learners also make judgements of instrumentality to justify earlier decisions or actions. Thus the requirement to actually make their design provides for the exertion of a whole range of judgements that enable fuller reflection on whether earlier decisions were even realistic.

9.3 Learner Experience of ALL

There can be little doubt that ALL engages and immerses the learner in their own learning processes. In observing the learners in different ALL environments there is in the majority of cases a noticeable enthusiasm, an urge to solve the problems they are presented with. Many of the learners in these case studies relate experiences that suggest they found ALL to be challenging and compelling. Learner groups regularly invested additional time to convene team meetings or do additional work to ensure team success indicating a greater tendency to be self directed and focussed on achieving a good outcome. According to Jarvis (2006:154) this phenomenon is a distinctive feature of active learning. Learners however do not spontaneously report enjoying the process, the re-collective narratives of interviewees would suggest that they found aspects of ALL to be frustrating and stressful, particularly where they see their own marks affected by the vicissitudes of team work. Sometimes the participants perceived a distance or reluctance to engage in the environment by their peers. This may be due to group work or social issues or it may be that some learners prefer didactic environments and a proximity to the authority of a teacher. These issues are not examined in this thesis but the incidence of low participation and dissatisfaction appears high enough to warrant investigation. It should be recognised however that while there is an expectation that ALL provides a stimulating experience, not all activity is purposeful unless the learner can intend the consequences of executing their urges to solve the problem, a condition that is not possible without judgement (Dewey 1938:69 & 84).

Some learners expressed difficulties coping with uncertainty. They were reluctant to expend effort in what may be a misdirected venture and tend to seek clues (even subtle ones) and guidance to what is expected of them for the purposes of assessment. In pedagogic paradigms that focus legitimately on the quality of outcomes, students direct efforts to gaining the highest number of credits for the least effort (Khaneman 2011:35). The urge to produce a 'good outcome' is evident in all the case studies. There does not appear to be an appreciation among the learners that learning is a process in which they form purposes in addition to goal seeking. Good outcomes are not necessarily indicators of sound judgement.

The degree to which the problem space was defined by the project specification is examined in case study 4. Third year full time students with industrial placement experience and part time industry students could have experiences that enable them to exercise judgements about the best way to present their designs and supporting information and documentation. From the records students can be seen to express disagreement about the necessity of some of the outcomes they were asked to provide. In other cases a good outcome may result purely by good fortune in spite of poor and reckless judgements. The incidence of heuristic judgements in case study 3 and the lack of awareness of the consequences by the students is illustrative. If there is to be a focus on developing judgement capacity there has to be a paradigm shift away from the expectation of merely producing good outcomes to place greater emphasis on the processes and thinking where judgements may be evident.

The specific prescription of objectives in assessment criteria to some extent defines the initial problem space for the learner. This is potentially disabling of the necessity for any judgements they would otherwise have to exercise about what they should include or exclude in their final projects. Being able to make appropriate judgements about the nature and even the scope and extent of a presentation to a particular audience is an important skill that has no rules, viz it is not a matter of competence but one of judgement. In professional practice if they were to make a presentation to a client about their design they would have to make those judgements in addition to any judgements related to the technical and socio-technical demands. The client will have an intentionality of the ideal presentation but would not specify them in advance. This raises important considerations about the purposes of assessment. Criteria implicitly establish rules or anchors by which a learner intends the extent of a problem space by being given a boundary. In such cases a problem cannot be considered to be truly open but is bounded by the rationality and intentionality of the tutor and their capacity to design ALL activities.

9.4 Exertion of Judgement in ALL

ALL is diverse and although there are numerous initiatives that are thought to be examples of it, it is an interesting question to consider if there is a unifying principle common to all ALL environments? ALL appears to be the pedagogy of choice for improving student engagement, retention or student satisfaction though not all studies have demonstrated this. It is also considered to provide a deeper and more complete learning experience. Activity is a central idea and learning through action thought to be important. From these studies it can be concluded that for the purposes of exercising judgement, physical action is not altogether necessary and the most important aspect of learner experience is the activity of discovering the solution of disjunctures in the problem space. Disjunctures themselves do not wait to be discovered, they are generated by the activity of discovering unknown parts of puzzles, inquiries and the conflicts between competing ideologies, practices, rules and beliefs. The learner caught in the flow of the learning experience is halted by the disjuncture and in exercising judgement, changes their intentionality.

In the case studies, learners were observed immersed in active learning in four environments that had both distinct and common engineering aspects. The categories of judgements observed were in part dependent upon the type of problem space. Projects that examine events retrospectively invite judgements of causality and factuality whereas constructive projects tend to judgements of hypotheticality and practicality. The rationality of the judgements exercised however, is more dependent upon the cognitions of the learner and the stage of development of the problem space. In the early stages heuristic judgements were dominant as the learners made rapid assumptions about the validity and appropriateness of relevant information. More generally, as the problem space definition improved the learners confirmed their definition of the problem space on the plausibility of their ideas and began looking for confirmatory evidence. At that stage, if confirmatory evidence was activated it reinforced the plausibility of their initial heuristic judgements. If they discovered or invented contradictory evidence they became sceptical of the contradiction and generated arguments to support their initial ideas This is particularly noticeable in case study 1. That is to say they constructed a disjuncture and had to expend time and effort to resolve it. It can be seen in the cases studies that heuristic judgements are not only exercised readily but if their validity was not considered or contradicted it became entrenched and indistinguishable from fact. The admission of new information to the problem space does not automatically guarantee a revision of intentionality, the learner has to do work in order to change consciousness. Heuristic judgements cannot be easily suppressed so the point of disjuncture is where knowledge and ideas have to be challenged. That is the point where most crucial judgement is exercised and it is at this point that learners need to acquire skills in assessing the veracity of those judgements.

9.5 Factors that Promote the Incidence of Disjuncture and Exertion of Judgement

9.5.1 Scope and Duration

ALL environments that maximise the occurrence of disjunctures in the flow of experiences provide for the greatest exertion of judgements. An effective environment had the following attributes. Activities that had more complex problem spaces required the learner to cope with more information. The emergence of new information competing with other knowledge and the rationality of the learner increased the potential for disjuncture. The problem space is not linear and previous states are revisited so the duration of the projects affected the number of instances in which disjunctures could occur, and consequently, the extent to which the learners could exert judgements. The incidence of disjuncture did not automatically mean that learners are having to make more difficult judgements nor does it mean they will ultimately make more sound judgements. Coping with complex environments where time is limited induces stress and learners resort increasingly to heuristic judgements that are prone to reasoning fallacies. To exercise sound judgements the learner must acquire the skills to understand when heuristic judgements were made and the extent to which they have informed or deformed the problem space.

9.5.2 Team work

The ability to work effectively in teams is a ubiquitous objective in professional development. All of the ALL case studies in this thesis involve team work in some form. In most cases team function was not prescribed and was left to the learners to determine how to construct their teams and how to conduct the affairs of the team. This effectively means the teams had to define problem spaces and reach satisfactory conclusions against a back ground of unpredictable and potentially irrational behaviours. When teams function well tasks and cognitive loads were shared but often at the expense of having to cope with each other. Team work is a skill that has to be developed but the irregularity and unpredictability in team environments and the associated cognitive biases are not conducive to the acquisition of good patterns in reasoning or the exertion of good judgements. *Primus inter Pares* effects appear to some extent in most of the teams that were observed. See section 2.2.3. Examples can be found in Case Study 1, 4th Observation of Group 1; Case Study 2, 1st observation of Group 2; Case Study 3, 3rd observation of Group G and Case Study 4, Group N in 11.2.1 Semi-structured Interview 1 and 11.2.2 Semi-structured Interview 2. where work and responsibility for key actions was subconsciously deferred to 'leading' individuals.

Unusually in Case Study 2 (the apprentices), 4th observation of Group 4 the oldest team member attempts to act as Primus and is strongly resisted by the other team members. There may be a number of reasons that account for this difference between the undergraduates and apprentices. I suggest that the undergraduate teams have been constituted only for the duration of the project and may still be in a social interaction phase that promotes team coherence and possibly group think. The apprentices however are in the second year of the enhancement programme and also know each other well from daily work and other college activities. This familiarity could have provided the team members with a perception of a more concrete appreciation of each others' capabilities thus preventing that individual from assuming the Primus contrary to the other team members' assessment of him.

The incidence and effect of Group Think is difficult to assess in the case studies. There is no general trend and there is variance across the groups observed. Some tendency to voice disagreement is evident and some groups do not entirely agree with proposed solutions. The criteria proposed by Janis (1982) are not strongly evident for group think though there are some cases of antecedent conditions such as group cohesion or organisational defects. The students' dialogues contain examples of disagreement indicating there is a general sense of empowerment. The following examples are illustrative.

Case study 1

> "Bird strike? I'm not sure about that but two of the girls are sticking with that idea."
>
> "M isn't convinced but unless he has an alternative argument!"
>
> "We'll present both hypotheses - there is no definitive answer."
>
> "I think it's a stall or a bird strike but they are dismissive."
>
> "Not a group still have this in mind! Come on!"
>
> "It says a flock of birds not one!"
>
> "So what?"
>
> "We should start writing the presentation."
> "But not until we have all the information and a common point of view."

Case study 2 apprentice group 4 is probably an extreme case when on occasions team members stopped working collaboratively. Group 1 lead stated there were issues with a team member;

"I have an issue with person X"

"He's being really.., I dunno, awkward?"

"At that thickness we'd have through holes and dowels and we don't want that, dowels aren't fitted in through holes."

"Let's thread the dowel pins then."

"Then they won't be dowels."

The other two group's members however engaged with each other and expressed their views freely. Some of the difficulties encountered by the groups in this case study were external effects and cannot be considered to be group think. The risk version and effects of money priming are an example.

Case Study 3 shows similar interactions indicating robust and constructive engagement.

“I need cost and material for manufacturing and sizes to put into the CES software. I don’t think forces are needed for the report.”

‘Yes we do, for strength etc. We need a free body diagram for this.”

“Guys according to the Gantt chart we are falling behind.”

“It's not that bad.”

“We’re behind, the deadline is by Xmas.”

“Need to complete the FAST diagram, when do you want to meet? Tomorrow?”

“No later today! You know the problem is you haven’t done anything!”

“Tomorrow is better for me.”

In Case Study 4, the members exchange views freely.

“To keep the character of the building we have to extend it lengthwise.”

"Extend the lecture theatre for access from the other end."

"It makes much more sense to go into the staff car park and double the height of the foyer space."

"What about roof access for the lifts? And we need a steel fire escape."

"Not sure about the space, why go on the roof in the first place?"

"Shall we start?"

"I want to wait for N." (N is sole architect in this group)

"Just put another row of columns here."

"Won't that totally screw up everything? - Move these?"

(Architect) "No! They will wind up in the middle of the lecture theatre. The columns fine it's just the wall."

There were group cohesion issues and organisational structure defects in some of the groups. Lack of proximity to other group members and low or zero participation from a minority of learners was evident in all undergraduate groups and to a lesser extent in the apprentice groups. This is most often reported in the semi-structured interviews and reflective precis. Despite the potential impacts upon group success and individual marks, teams were disinclined or unable to seek ways to resolve the problems and this placed the burden of success on more proactive students.

Individuals working in teams may in some cases work in isolation with only sporadic interaction between other team members. From the case studies can be seen numerous exchanges where learners are expressing their intentionality through ideas. These exchanges drove the formation of a collective problem space and in that formation some or all of the participants in the dialogue experience a change of intentionality. That is to say the way in which they perceive and understand the problem space changes. Where interaction is enabled the incidence of dialogue increases dramatically and with dialogue comes the exchange of ideas and knowledge that promote disjuncture.

This process is gradual, there are rarely any sudden 'Eureka' moments where this can be demonstrated explicitly. It doesn't happen in all cases and some learners cling to their original world view whatever evidence is presented. This can be evidenced in those groups where split decisions occurred. However I will say that dialogue is probably the most important factor in the construction of disjuncture. Without dialogue in a group, the representation of contrary ideas, conflicting viewpoints and re-activations of knowledge to others is severely limited and one party cannot influence another. Disjunctures are only potentialities in an environment until the learners, in the process of representing their ideas to each other, activates them through the connections they make between knowledge states. The following examples are provided to illustrate this.

From Case Study 4 Group N;

> "What about the roof? Do we have a green roof?"
>
> "It impacts on the loading and if there's no access to it how can it be maintained?"

This is a disjuncture, the break in the flow of an idea that demands resolution before the idea can be progressed or dismissed.

> "We could have a lift going up to the roof."
>
> "It wouldn't need heavy equipment just a trimmer etc."
>
> "I'll have to check the structural implications."

Another disjuncture, interrupts the flow of the 'green roof' idea demanding the loading issue is resolved. This particular disjuncture will generate a judgement (an intentionality) that either progresses the green roof or closes it down.

The following exchange is also from Group N and was initiated by the architect who wishes to visualise an alternative design. The engineer indirectly presses the architect to reconsider because of loading problems that she is unaware of.

> "Put the stairs here and move these columns, can I have a balcony here to justify that?"
>
> "We'd need to see if the additional load on the existing foundations is acceptable."
>
> "If we use the existing foundations we have to prove our design by calculation."

> "Just move the stair so that I can visualise the whole thing. If we didn't need those columns there what to do with this open space?"
>
> "If we move the columns to the edge we load the existing foundations which we don't have calculations for!"

In the dialogue below from Case Study 1, group 1. the students are trying to resolve the sudden loss of mass from the aircraft. The disjuncture is constructed on their conflicting perceptions of the loss of mass. A fuel leak was reported before take-off and the conflict lies between a loss of several tons of fuel in under a second or structural damage. The fuel leak looks plausible except the rate of loss is too big and they can't explain it until one proposes a wing breaking off.

> "The rate of turn indicates an evasive action took place."
>
> "There are massive changes in X! I don't think this is a fuel loss!"
>
> "The incident angle goes from 97.5 to 4.6 in about a second, so a fuel leak is looking very plausible."
>
> "The leak doesn't occur until in flight and this is more than a little leak yeah? Sounds more like the wing has fallen off!"

9.5.3 Reflective Activity

Disjunctures can also arise in reflective activities in which judgements of counterfactuality, causality, and instrumentality are exercised. Reflective experiences may be of two types. A learner may recall past experiences and cogitate whether or not their decisions led to good actions or outcomes. Or subsequent activities can force the re-activation and re-appraisal of earlier decisions. Recollections of the past are not fixed or perfect but volatile and susceptible to alteration and an objective view of past experiences is difficult (Khaneman 2012:381). This conflation between experience and memory was also evident in Case Study 3 (10.2) where the students had imperfect recollections of external factors that affected their decisions.

It is even likely that weak reflective practices could generate associations that are imperfect by convincing the learner that their judgements were good when in fact they were anything but. For learners engaged in an activity that demands the re-activation of earlier experiences and knowledge states the degree of congruity between past knowledge states and current intentionality is strikingly obvious to the learner. Referring to Case Study 2 (9.2) subsection machining phase, the realisation they have incorrectly dimensioned a fixture plate that leaves no room to mount a cam is undeniable. The re-activation of experience while trying to execute a current action constructs the disjuncture. The learners were confronted with the effects of a past judgement forcefully and accurately. It was not possible for them to distort their past experience while they are confronted with the evidence. Moreover they had to recover from their dilemma by proposing and enacting a solution to the setback they had created. Disjunctures thus constructed are very powerful learning experiences though in many learning experiences it is not always possible to create the necessary environment. The following quote from Dewey (1938:87) is illustrative:

> "Ideas and hypotheses are tested by the consequences which they produce when they are acted upon, This fact means that the consequences of action must be carefully and discriminatingly observed. Activity that is not checked by observation of what follows from it may be temporarily enjoyed, but intellectually it leads nowhere".

9.5.4 Complex Environments

In the initial stages of the research study it was conjectured that problem spaces that are complex due to high technical demand and ill-defined socio-technical constructs would provide more opportunities to exercise judgements and that the exercising of judgements would present greater difficulties and be more redolent of professional practice. The first assumption is probably correct and it can be seen that complex environments will have more disjunctures that are difficult to resolve. The second assumption however can be challenged. From the case studies it can be seen that relatively well structured environments with modest technical demands still created the impulses and opportunities to exercise series of judgements. This would suggest that a learning environment constructed appropriately for the purposes and capabilities of learners at a particular level may still enable the exertion of complex judgements.

A dialectic emerges between constructing a complex environment to enable learners to acquire wicked skills and on the other hand having an environment that is sufficiently regular for the learner to discern patterns in reasoning and see the consequences of their judgements. Both scenarios appear plausible however heuristic judgements that are prone to error are ubiquitous irrespective of the problem space. To develop those kind of judgements to the point that they can be relied upon suggests that they need to be exercised and evaluated in more regular environments where the patterns between knowledge, judgement and intentionality are more readily perceived by the learner and where the consequences of judgements can be more easily seen in reflection on activity. It also suggests that repeated exposure to regular patterns over a period of time is necessary. This conditioning is what we expect to see in the way professionals develop judgements in everyday practice and is discussed by Khaneman (2011:237,243) and in sections 2.2.1, 2.1.4, 2.1.5 and 2.3.2. This argument does not mean that ultimately wicked problems should not be used at all but it makes the case that before the learner is exposed to them, they need experiences in making judgements in regular problem environments and that they have developed skills in knowing what types of judgements are being made and under what conditions those judgements are reliable.

In a sense, exposure to regular environments may be argued to be the learning of tacit rules of judgement and it could even be inferred that a function of formalised process management strategies is to produce regular environments.
This phenomenon cannot be readily seen in Case Studies 1 and 2 because the learners were in novel environments and there are few concrete analogies on which they can draw even over the duration of their projects. In Case Study 3 there is an emergence of the phenomenon where learners have begun to form analogies from previous projects. The following extracts illustrate that learners are relying on previous experience analogies to make judgements of relevance and composition about the problem space. At this stage there is little indication they have acquired any implicit skill in heuristic judgements of the validity of the technical arguments.

Team K: 11th February 2014

> "Has anyone got a Pugh matrix? Can we narrow it down to 3 from our data?"
>
> "The PM calls for a datum do we select one of our designs?"
>
> "Normally we'd select from a current market product."
>
> "What do we select on?"

"Aesthetics, cost, ease of use, ease of maintenance, ease of manufacture, ease of storage (compactability)."

Team K: 12th February 2014

"3 – 4 free body diagrams with text"

"We got marked down for free body diagrams and calculations last time so..............."

"The FAST diagram is half done."

"We need to decide the market, whether to go expensive or 'bog-standard'."

"An initial needs analysis is part of the project spec."

"We need three detailed concepts, as detailed as we can make them."

Complex socio-technical environments that are not readily identifiable or measurable run the risk of being cognitively over loaded so the learner cannot take into account all the disjunctures in the problem space and see the consequences of their reasoning. Learners rely increasingly on heuristic judgements to resolve reasoning conflicts in complex environments because there is no quantifiable or measurable rationality in those problems. This can be seen in Case Study 3: (10.3) where the reduction of the problem space relies on heuristic reasoning in a Pugh Matrix. Learners also tend to heuristic reasoning when the problem is perceived to be technically demanding though this is much less evident in Case study 4 where the students are 3rd year undergraduates who have greater domain specific knowledge have become more confident in dealing with conflicting concepts and intuitively know when they need to resort to evidence to make a judgement. Students in this category have also matured cognitively.

Many socio-technical issues in which heuristic judgements are exercised are value ridden and susceptible to distortion from the systems of belief held by the individual. There are no algorithms to readily resolve such matters and heuristic judgements are probably the only way to resolve fuzzy or wicked problem spaces. This type of judgement is quick and effortless, and in the exertion of a heuristic judgement the individual learner does not actually have an increased cognitive load as a result of the wicked nature of the problem. Heuristic judgements simplify complex problems at the expense of introducing errors that are often unnoticed and remain latent providing the consequences are serendipitous. One of the positive functions of heuristic judgements is to reduce seemingly intractable problems and concepts so that they are easy to cope with. Negatively, any difficulties are under estimated and even irrational decisions are made with extraordinary confidence. Heuristic judgements however are not reliable and are less likely to produce predictable consequences in an uncertain and variable environment. In hindsight, heuristic judgements are seen to be more rational than they actually are. This means that working in increasingly wicked problem spaces could be potentially deleterious to the development of sound judgement capacity. To proceed in an environment that is uncertain or lacks information a professional has to be able to rely on analogies from experience but those analogies may not be correct and so to achieve true professional judgement capacity the learner must have developed the capacity to know when judgements are fallible and proceed accordingly. One purpose of reflective activity in a learning curve could be to understand the type of judgements being made and to acquire skills whereby the learner and professional are more sceptical of the validity of their judgements.

9.6 Professional Judgement

The development of professional competences within the community of practice model is considered in 2.1.4. To establish whether ALL can promote the development of judgement capacity it will be useful to draw some comparisons with what is generally understood about professional practice and what can be inferred from the case studies. There is an expectation that a professional will develop a high level of skill in judgement over time. However the expectation that this is always the case in a completely random process without knowing what sound judgement actually is, does not sound reasonable.

The case studies present the learning environments of young people embarked on a process of acquiring professional skills. Judgement capacity is not generally a pedagogic objective and it is assumed that people might develop judgement capacity as a result of being educated for knowledge. This may be true to the extent that by comparing the reasoning of students in the case studies it can be seen that the more mature learners have acquired implicit rules in the exercise of judgements over time. Simply asking someone if their judgements were good or improved during an intervention however is unlikely to produce meaningful responses. The issue is that they are unaware of the types of judgements they made or in what ways any of their judgements may have improved. Cognitive biases will always affect a learner's perception of their own judgements unless there is a specific intervention that raises their awareness to the point that they become critical and sceptical about the validity of their own judgements. Active learning can implicitly promote the development of judgement capacity but it would never be clear to what extent this happens or it could be constructed for the purpose of promoting judgement capacity by educating for knowledge of judgement and reflective practices that acquire habits of sceptical inquiry.

9.7 Limitations and Benefits of the Study

9.7.1 Tools and Methods

Four case studies were conducted and detailed observations made of the learners activities in ALL projects. The study employed different methods of collecting data about the learner's activities. For the purposes of assessing judgement, manually recorded observation and logbook audits presented a rich environment from which judgements can be readily inferred. Semi-structured interviews provided useful perspectives but the learner's re-activation of memories was subject to hindsight and confirmation biases and some accounts may have been incomplete, selective, merely wrong or all three. Reflective precis did not work as well as expected. It was anticipated that they could give a 'learner's eye snapshot' of a session and in some ways provide a tool similar to a log book page but in practice they were difficult to implement. Learners had little time to complete them thoughtfully so that responses were not as detailed as hoped.

The limitations of observational tools is their dependence on dialogue and action. It was not possible to infer judgements as they occurred from a team that was working independently and in silence. They would still have been making judgements (possibly in a limited way) but there were no judgement 'residues' to work from. It was

sometimes possible and in some cases, to put a question to such a group and get a cascade of information about what they were doing.
Logbooks are often limited in the amount of detail that the log keeper provides and this can vary significantly. Learners needed coaching and practice on how to complete a logbook entry that provided useful detail and some were much more assiduous in this task than others. They did however improve noticeably. The difficulty of getting learners to maintain written records was noted by Bramhall et al (2012) in a study on the use of portfolios in aiding success and employability, see 2.3.3. An interesting example of learners' intentionality and problem space definition was recorded in that study where the authors stated:

> "They basically had a clear idea of what they thought would make a well-presented portfolio, but complained that they did not know what to include in one."

Here can be seen firsthand that learners can in fact exercise initial heuristic judgements of composition about an uncertain problem space without guidance. When they attempt to define the problem space rationally they have to exert system 2 judgements and suffer some degree of stress. The urge to seek an easy route to the answer is compelling. The learners soon complain they need more guidance and feel dissatisfied when it is not presented in an easily digestible form. Bramhall et al (2012) gave the students 'shadow mentoring' on what might be included without being prescriptive. In conclusion, implementation of the framework, places reliance on the learner and would depend on how well the learner is prepared and enabled for the task. An advantage of the logbook system is that learners who use it well provide audit trails of all their decisions reducing the tendency to hindsight. A log book also includes those judgements that are made 'offline' when dialogue is absent whereas direct observation can only detect what is given during the observation.

9.7.2 Inclusion of Learners in Work Based Learning

The challenge in Case study 2 was developed by me. There were several aims in the development of the programme. It had to incorporate the employer's expectation of required training from a broad syllabus. They also wanted me to provide a different approach to learning and from my point of view it had to flow and extend knowledge and principles gained from their 1st year work. An ALL intervention was developed that covered 70% of the syllabus and incorporated, materials, CNC machine structures, jig and fixture design, cutting tool design, and cutting forces and CAD systems and metrology from the syllabus and allowed the extension of earlier work. For example trigonometric methods used for programming arcs can be used to examine cutting forces and free body diagrams.

The relationship between me as a participant tutor/researcher and the apprentices was qualitatively different to that between me as a non-participant researcher and the students. The apprentices were in the 2nd year of a 66 week programme taught and facilitated every week by me. In that time they have acquired implicit rules and are aware that their judgements, actions and decisions are being scrutinised. As their tutor I am perceived variously as an authority and provider of knowledge, and a mentor and advocate as well as critical examiner. This builds a degree of rapport. I did not have the same rapport with undergraduate students whom I did not tutor and whom in some cases I did not see regularly. Communication was therefore more difficult in the case of the undergraduates. Some were disposed to contact me and invite me to their extra tutorial meetings and others would not. It was time consuming and difficult to maintain contact with a undergraduate groups out of normal tutorial times.

Extending the research outside of undergraduate provision at Coventry University to include apprentices in a work based environment had beneficial implications for the study.

A broader research field, suggests that the results were not solely due to a local effect, strengthening the argument that ALL promotes the exertion of judgement and this may be considered to be independent of the location and type of learner, or that it is intrinsically predicated on a formal educational environment.

Undergraduate students therefore could theoretically complete the first parts of a project or learning intervention on campus and complete concluding parts in industry during a work experience that was set up for that purpose in collaboration with an employer.

The results suggest a good correlation for the development of judgement capacity between the formal educational objectives of preparation for employment and the semi-formal training of employer needs for the development of effective employees.

9.8 Judgement development in ALL

9.8.1 Overview

The results indicate that the use of ALL interventions to develop judgement capacity may be framed in two discrete but related paradigms. Either of these could be usefully implemented in both formal and semi formal educational settings. ALL environments can usefully provide a range of experiences in which the learner has to exercise judgement that generally appears to be largely irrespective of the discipline or the nature of the problem space, excepting that some problems are more conducive to the exertion of certain types of judgement. In investigative projects (see Case Study 1), judgements of causality mediated by judgements of hypotheticality are commonplace whereas in typical constructive projects judgements of hypotheticality and practicality are prominent (see Case Studies 2, 3 and 4)

9.8.2 Principles of Judgement in ALL

In ALL as it is currently defined and delivered at Coventry University, the learner may be aware that they are expected to develop reasoning skills but they are unaware of the true nature or validity of their judgements. The development of judgement capacity may be considered intrinsic to the ALL paradigm where the learning environments are sufficiently regular. It may be reasonable to assume that for most well planned and delivered interventions the duration or diversity of projects encountered over a 3 year undergraduate programme or an extended semi formal work based programme implicitly provides such an environment. Providing that the environment is active, viz there are disjunctures that interrupt the flow of intentionality, the learner can make judgements, form purposes and construct new intentionalities. In such a model we can say that judgements are usefully exercised. If it is to be assumed that the learner develops judgement capacity in these circumstances then the ALL interventions need to flow into each other in an environment that is sufficiently regular for learner to be able to acquire analogies where the outcomes of their judgements are predictable.

From this, it can be asserted that ALL can be assumed to implicitly promote the development of judgement capacity and I refer to this assertion as 'The Weak Judgement in ALL Principle'.

In considering whether ALL promotes the capacity of judgement as an explicit development in professional skills then it is necessary to consider on the evidence whether ALL interventions can be constructed to enable that process. ALL provides opportunities to exercise judgement in complex problem spaces and these may be likened to the complexity of problem spaces encountered in professional engineering practice. The incidence of judgements is dependent upon the opportunities presented and experienced but the soundness and exertion of judgements depends upon on the cognitive capacity and intentionality of the learner. The limitations of working memory and the computational effort in system 2 thinking, increases the incidence and reliance of heuristic or system 1 judgements. Complex environments and in particular wicked environments where concepts and problem end points are altogether vague, and knowledge is uncertain or absent also promote heuristic judgements because there are few ways in which a problem space has formal rationalities.

The confidence with which heuristic judgements are made is extraordinary and the chances of them being wrong are appreciable. Over confidence is a major factor in planning fallacies and it is unlikely that heuristic judgement performance can be improved merely by having the chances to practice. Improvement can only come from recognition of the weaknesses inherent in heuristic judgement and the need to become sceptical and seek evidence on which to base sound reasoning. An educational programme for the development of professional judgement must provide the individual with the skills to recognise, assess and ameliorate heuristic judgements in order to improve overall, the judgements they make as professionals. If it is asserted that ALL develops professional judgement capacity then the ALL intervention must be constructed to increase the learner's awareness of how they have made certain judgements and to make them more critical and sceptical of judgements made by themselves and other agents. I refer to this assertion as 'The Strong Judgement in ALL Principle'. The principle is set out chapter 10 in a six point proposal for an ALL framework.

9.8.3 Recommendations for Practice

To exercise the faculty of judgement ALL scenarios should promote self directed learning and the construction of knowledge. For those purposes ALL should be appropriately minimally guided to enable the learner to define the initial problem space conditions for themselves and progressively redefine it until they have reached a solution. The initial activity of problem space definition involves the exertion of heuristic judgements to reduce the initial problem space to manageable proportions by forming their own propositional attitudes Lipman (2003:20). Reducing the level of specific guidance and performance criteria of the project specification increases uncertainty and promotes disjunctures that compel the learner to define problem spaces in the same way that professionals do by exercising judgements on what the problem requires in order to solve it.

In the early stages of a programme, learners are uncomfortable with uncertainty and seek more specific guidance or at least some confirmation that they are on the right track. In some cases learners even become susceptible to subtle cues and anchors from tutors. In the first year of study, ALL learners may be exposed to particular techniques and procedures for problem solving and project management that make learning environments more regular. In such situations it becomes easier for the learner to infer the consequences of their decisions. They will also acquire through this some knowledge and analogies that can be re-activated in other learning activities.

However, as the learner develops throughout their programme of learning they should be provided progressively, with project specifications that are increasingly ill-defined in order to create more opportunities to define initial problem spaces for themselves. Thus by their final year of study they have developed professional skills in realistically assessing the scale of the challenge, the tools and methods that they will adopt and the evidence that they will present as having completed the problem. A project specification that tells learners explicitly and in detail what they will provide for assessment may provide a framework for practice but is not conducive to developing these skills.

The project scenario should create the potential for disjuncture viz the solution should not be so apparent as to be discernible without cognitive effort. Scenarios that are complex and have conflicting data provide engaging and stimulating environments for discussion as well as the exertion of judgement and the formation of purposes. The four case studies in this thesis present disjuncture in different ways. By way of example, case study 1 creates the potential for disjuncture through conflicting information sources and evidence. The disjunctures in case study 2 arise in the tensions between seeking optimal technical and commercial solutions in a complex research environment and the actual making of a design. In case study 3 the disjunctures arise from changing specification and the challenges in optimising a design for a particular market. In case study 4 disjunctures arise in coping with the demands of interdisciplinary team work and in critically compromising between rational and socio-technical demands of a complex project. The case studies indicate that all of the project information should be available for discovery by the learners from the outset. Information that is not extant cannot be retrieved and while some learners identify the need for additional information, many learners tend to stall at some particular optima due to the coherence or plausibility of an explanation from the data they have access to. The absence of relevant data can disable or delay disjuncture, though altering a project specification can create circumstances that result in disjuncture but it should have some justification, for example it could be presented as a client change to requirement.

The inclusion of team work enables the possibility of dialogue and this may be considered a central activity in the promotion of judgement and reasoning through communities of inquiry. Dialogue is more than a conversation; it permits deliberation and conflict and the potential for learners to generate their own questions and self correcting behaviours (Lipman 2003:96). ALL delivery strategies should create opportunities for groups of learners to form effective teams. Promoting participation in the community of inquiry should be a function of any model of ALL delivery involving team work. If it is left to learners there is enough evidence that it doesn't always happen and learners are aggrieved at the low participation of other team members. It was noted in case studies 1 and 3 and to a much lesser extent in case study 4 that some learners tended to sit remotely from other team members and this is inhibitive of dialogue. This phenomenon is not unusual in communities of practice (Handley et al 2006:644) where individuals may not seek full participation or may not be even permitted to achieve it.

Wherever possible teams should be sitting in proximity to the group to which they have been assigned to work with. Incorporating the requirement of all team members to collaborate on planning and delegating team work at the beginning of each session promotes team cohesion. It also enables visualisation and re-activation of the current problem space and focuses the team on concerted action rather than just assuming that things will happen. Case study 2 reveals the potential of keeping a logbook or similar record that preserves chronologically, a record of proposals, decisions and actions. It is unlikely that every person in a team simultaneously thinks of exactly the same proposition or decision and so records should not just be generalisations of actions such as "We decided to do.........". A logbook should be a detailed record of who made particular proposals, who voted for and against decisions, who carried out particular actions and the individuals views and critical reflections on those decisions. In addition to the activity of planning in team cohesion, the logbook provides a strong body of evidence for critical thinking and judgement that is almost free from hindsight or confirmation biases. Furthermore it is a much more objective way of assessing the relative contribution of individuals and their thinking than relying on the hindsight accounts in learners' peer reviews. From a detailed logbook the tutor or assessor can see who has done the innovative or critical thinking and who has been passive and this can become an objective basis for the distribution of marks.

For All to promote judgement capacity under 'the strong judgement in ALL principle', specific interventions are needed to enable the learner to acquire a criticality and scepticism of the judgement per se, of their own heuristic judgements in particular and an awareness of common biases in reasoning. Lipman (2003: 70,72) makes the case that distinct and discrete modules on critical thinking that are just appended to curricula risk being superficial or even irrelevant. I will say that these assertions by Lipman are possibly correct and in the context of ALL and situated learning, the learner should acquire criticality by examining their judgements as a function of and in the context of their own practice and discipline.

Heuristic decision making systems are cognitively dominant and the mental effort in system 2 rational thinking is one of the principle reasons that humans fall back on fast heuristic decision making. Consequently learners seek ways to optimise effort in gaining marks and they tend to be less satisfied and spend less time on those aspects where the rewards are perceived as disproportionately low for the effort involved. This suggests that the distribution of marks for assessable components with heavier cognitive demands, should in the balance attract a higher weighting. ALL interventions that compel learners to invest effort in the development of judgement skills must have an allocation of marks commensurate with the effort and the importance attached to its pursuit otherwise it is unlikely to be given serious consideration by learners or tutors.

10. Conclusions and Recommendations

10.1 Overview of Chapter 9 Discussion

In Activity Led Learning, factors can be detected that promote and impede the exertion of judgement. Different types of problem space tend to the predominance of different categories of judgement. All problem spaces irrespective of the knowledge domain are dominated by heuristic judgements before the emergence of formal rational judgements. The incidence of heuristic judgements is such that while the complexity of a problem space provides for more complex disjunctures it does not make judgements cognitively more difficult because heuristic judgements are relatively effortless. The increased levels of uncertainty, absence of knowledge and difficult to quantify issues however would tend to make heuristic judgements more unreliable. The practice of exercising judgement alone cannot be assumed to improve judgement unless the learning environment and its outcomes are sufficiently predictable for the learner to discern accurate associations. The implicit rules acquired of prolonged practice in a regular environment can provide some analogies which may be extrapolated into more complex problem spaces but are unlikely to prove completely sufficient. There is a need for learners to acquire skills in knowing what judgements are exercised, to know in what conditions they are reliable and when they should be sceptical of their judgements.

10.1.1 Main Conclusions

The main conclusions from the study as a whole are summarised here.

The study has demonstrated that typically learners within an Activity Led Learning setting do not solve problems by progressive stages in a linear fashion; instead the stages of a problem are repeatedly revisited and knowledge re-activated to reach a solution.

Throughout the study it was observed that learners working in teams express cognitions as judgements through dialogue to build a shared experience of the problem.

Team work was a powerful construct for the promotion of dialogue. Through dialogue the learners expressed propositional attitudes to share their dissociated cognitions. The action of dialogue to share experience is a driving force in the exertion of judgement and the development of the problem space. This suggests that team working is an important factor to initiate states where learners can express cognitions and judgements through the dialogue that takes place.

Team work had negative aspects. Not all students engage fully and some not at all. The learners who emerged as *primus inter pares* found team collaboration and the management of low participation stressful. The typical response being to take on more of the work to mitigate the effects of low input from non-participants. When they re-activated experiences of their projects this socio-technical aspect was salient.

In the case studies within the research, the judgements expressed by the learner were affected by the learner's experiences and evolved cognitive biases, the extent of their rationality and the information available. Previous experiences that are readily re-activated are readily accepted as truths. This suggests that the presentation and flow of information and knowledge in a learning environment will affect learners judgement.

Judgements are attributions of what individuals perceive to be true and when that attribution is challenged by the admission of new knowledge a disjuncture is formed. A disjuncture is a state of dissatisfaction with the validity of current perceptions. It creates the urge to resolve the disjuncture by exercising judgements about its content and circumstances.

When learners exercise judgements about disjunctures they either confirm their current perceptions or change those perceptions to create new and revised knowledge and understanding. The incidence of disjuncture in the learner's experience provides opportunities to exercise judgements that are critical to developing new understanding and purposes.

Heuristic judgements are commonplace in human cognition and perception but are prone to error from evolved cognitive biases. The incidence of this type of judgement can be observed in ALL particularly in the preliminary stages of the activity where learners make heuristic judgements with confidence particularly when information is absent or uncertain. Some learners continue to exercise heuristic judgements throughout the duration of the projects even when the problem space is technical.

In the early stages of ALL projects, judgements are heuristic reasonable approximations. The problem space tends to more rational judgements when the learners recognised the current state of knowledge was uncertain and there was the need to seek and incorporate evidence that ameliorated the uncertainty.

Learners may acquire tacit skills in a regular ALL environment that make their heuristic judgements more reliable, that is, when the connections between judgement, decision, action and consequence are readily apparent to the learner. In such cases the learner acquires experiences and analogies on which they can rely when they encounter similar problems.

Regularity in ALL engineering environments can be promoted by the adoption of models and procedures such as project and risk management tools, Functional Analysis Systems Techniques, Pugh matrices etc. Regular environments promote pattern recognition and enable the learner to focus on discrete aspects of the problem space in a structured way. These procedures do not make heuristic judgements rational or necessarily promote rational judgements.

A prediction of this observation is that learners will have great difficulty in making sound judgements in wicked problems where such connections are not obvious. The complexity of a 'wicked environment' is due to the many connections and influences of knowledge-states and tends to make heuristic judgements of hypotheticality susceptible to notions of value and therefore increasingly unreliable.

The presentation of information in a project specification may have effects on judgement. Facts most easily remembered are those that are considered to be correct or the most probable, and the learners' initial problem space definition can be influenced by the detail in specifications and subtle cues from tutors.

It can be assumed that some learners exercise good judgements in Activity Led Learning environments. It can be assumed that over the duration of their courses the capacity to exercise better judgements may emerge. It cannot however be assumed that they implicitly acquire skills to improve or develop their judgement capacity without specific and purposeful interventions within ALL experiences.

Developing judgement capacity is dependent upon a learning experience that acquires skills in understanding assumptions about knowledge, the validity of kinds of evidence and knowing when heuristic judgements are risky and the need to resort to rational judgement practices. It requires in addition the development of skills in critical reflective practice. These principles should be given priority in a learning programme that is expected to develop professional judgement capacity.

10.2 A Framework for Activity Led Learning for Professional Judgement Capacity.

10.2.1 Introduction

Current ALL praxis does not have organised mechanisms by which the learner can determine the nature and validity of their judgements and therefore cannot be confidently assumed to enable sound professional judgement capacity. Organised procedures can be implemented to enable learners to develop reflective skills that increase their perception and criticality of their own judgements. The inclusion in ALL interventions of such procedures will increase the prospect of learners understanding the normality and utility of heuristic judgements while becoming increasingly sceptical of their validity. In consequence they may come to understand in what circumstances heuristic judgements are acceptable and when it is necessary to exercise formal rational judgements. A framework of principles incorporating an outline for a procedure is set out herewith.

10.2.2 An ALL Framework for Promoting the Development of Professional Judgement Capacity.

1. The scope and duration of the ALL environment must be appropriate to the level and interests of the learners in so far as it creates the urges to engage with and examine the problem to seek a solution.

2. The ALL environment must generate sufficient disjunctures through the intentionalities and actions of the learners for them to exercise numerous and diverse judgements and form new analogies and purposes.

3. ALL interventions must be minimally guided, permitting the learners to engage in dialogue and intend the initial and subsequent problem spaces for themselves.

4. The ALL experience must introduce learners to concepts of judgement in ALL so that it becomes possible to engage them in a meaningful dialogue about the judgements they exercise in context, the effects of cognitive biases and their consequences.

5. The ALL experience must have reflective procedures that use knowledge of judgements as critical examinations of the contexts and the mediating and culminating judgements that contributed to the construction of the solution.

6. The ALL intervention must have an assessment component that allocates sufficient marks to the execution of the learners' reflective procedures, their analyses and the validity of crucial judgements.

Point 1: This may be thought of as received wisdom for general educational purposes however, a problem or project that does not exercise the interest or curiosity of the learner to be a self directed participant in seeking the answer will not be active learning.

Point 2: Judgements that create new knowledge and purposes for learning to take place are cognitive responses to disjuncture. Circumstances that cause the learner to re-examine their current understanding and find new knowledge that satisfies the disjuncture results in a change of consciousness and may be considered to be true learning.

Point 3: Many projects are given to the learner in such a way as to guide them to the best approach to the solution. This is usual community of practice and is predicated on tutor master infallibility. Where the learner intends the problem space themselves they have to think much more about what an appropriate solution and its problem space looks like. Maximising the opportunities the learner has to exercise judgement increases the experiences on which they form analogies. To enable thinking and judgement, tutors must resist the expedience of forming pathways to answers.

Point 4: Self examination of the faculty of judgement necessarily begins with knowledge of what judgement is and how it is exercised. People tend to think their judgements are skilful, correct and rational. If judgement capacity is to be developed that assumption has to be challenged. The predominance of heuristic judgements increases the risk of decisions being inappropriate or even incorrect.

Point 5: The practise of reflecting on a project at its end stage risks the distortion of memory through hindsight bias. Individuals create narratives that fit their systems of belief and past events become more predictable than they really are. The learner must be engaged in a regular process of recording critical decisions and evaluating their reasoning and judgements as they are exercised before they start to invent the past. When the learner examines their solution in the context of the judgements they recorded then they can begin to understand to what extent their judgement contributed to the successes or failures of their project.

Point 6: Assessment models compel learners to focus on outcomes and seek maximum marks. An intervention must be allocated marks that address the cost benefit of the cognitive effort . (Wilson-Medhurst et al 2012) cite Knight (2007) on the importance of the type of feedback in assessment and the necessity to design assessment to engage students as participants.

10.3 Potential Impacts upon Teaching and Learning of Adopting the Framework

There are some issues that would need to be addressed if implementation of this framework were to be successful. Learners would have to receive some tutorial input on judgement concepts and practice in distinguishing types of judgement so that they have a better understanding of their own decisions and so that they can be engaged in meaningful dialogues about their judgements. This implies that tutors would also need staff development in the process. To determine and evaluate judgements objectively they must be recorded and evaluated as they occur. Preferably, through the duration of a project, the later stages of work will force the learner to re-activate earlier experiences and reconsider the judgements they made so that the validity of earlier decisions is brought into question. The regular and continual nature of this practice places the onus and burden on the learner. A tutor would not have the time or resources to monitor the process.

There are already interventions in higher education where students are required to keep portfolios or logbooks and exercise reflective thinking. Portfolios record experiences in a particular format for showing achievement. Logbooks however could be usefully employed. In the apprentices' case study the logbook entries were self appraisals of performance about how well they had planned and executed the day's work. From these records I could infer the learner's judgements. Maintaining a logbook to improve judgement would require a re-focus. The apprentices' logbooks record their decisions and actions with a section for them to reflect on whether planning was good or they made errors. The apprentices as yet do not assess their own judgements critically or have any great understanding of the validity of their judgements, they merely make an assessment of the successes and failures of their plans. In order for learners to be able to record and access their own judgements they would have to be shown how to record key decisions and how to use new knowledge of judgements to evaluate their reasoning and assess the types and validity of their judgements. A programme that included such an intervention would take time and guidance to implement with each cohort to develop any facility in those skills from the early stages of an undergraduate programme through to graduation.

A learner engaged in such an intervention is regularly confronting their decision making in a critical manner and should reach a point where they can distinguish different types of judgement and whether they are more or less subject to bias that affects the validity of their decisions. The learner should in time come to a greater awareness of when their intentionality may be at fault and resort to rational means to adjust their world view. The purpose however would not be to make the learner an expert in judgement but to enable them to develop skills about the judgements they make in the context of their own professional decisions. Judgement in the absence of information and uncertainty can be seen more clearly for the risky process that it is, over confidence about heuristic judgements can be mitigated and risks assessed with greater rationality. A learner thus equipped begins professional life with a much more useful approach to thinking and coping with decisions and is more likely to be able to make sound judgements in diverse and wicked problem spaces.

10.3.1 Assessment

The proposed framework involves an intervention that would have to become an assessable component in order for it to be successfully implemented. The semi structured interviews from Case study 4 (11.2.1 - 4) is illustrative of the way students equate effort with credits. Even before undergraduate life students have been led to consider achievement in terms of marks and grades and are unlikely to embrace an initiative with any enthusiasm unless the purpose is defined and rewarded. The rewards have to meet their expectations and judgements of value. Careful consideration therefore would have to be given to what percentage of the marks are given to this exercise. The specifications for projects in these four case studies indicate that reflective work attracts comparatively low marks. In specifications where it is explicitly given, the marks are typically 10% of the total assignment. In the Case study 4 and Case Study 2, students are informed that reflective practices contribute to overall and individual marks but without explicit specification. There is a slight implication of coercion in the specification in Case study 4. If current reflective practices were adapted for learners to use in assessing judgement I would say that greater weight would have to be given to that aspect within overall assessment so that the development of judgement capacity is accorded some degree of importance as a pedagogic and self development objective.

10.3.2 Summary Analysis of Assessment Instruments

In this section a proposal is set out for assessment instruments at each level of a 3 year undergraduate programme in engineering. Assessment instruments for engineering apprentices who are also studying for the Higher National Certificate in Engineering are nominally at the same level as first year undergraduate learners at QCF level 4.

Within the 'Weak Judgement in ALL Principle' the core assumption is that learners may develop some judgement capacity by virtue of exercising judgements in ALL environments that are sufficiently regular for the learner to be able to discern the relationship between their judgements and the consequences. Starting at QCF level 4 it is reasonable to suppose that the learner needs greater levels of guidance and support and that the project specification will have sufficient detail to convey to the learner the breadth and depth of an ideal solution to the problem space. At QCF levels 5 and 6 the project specification should enable the learners increasingly greater latitude in problem space definition and the learners should have less specific guidance with regard to what evidence they have to submit. This system is predicated on the need to carefully structure assignments and materials in such a way that knowledge flows into subsequent assignments in a way that the learners can import analogies and experiences from previous learning on which they can base their reasoning. Fig 7 illustrates how this might work in the context of engineering problem space.

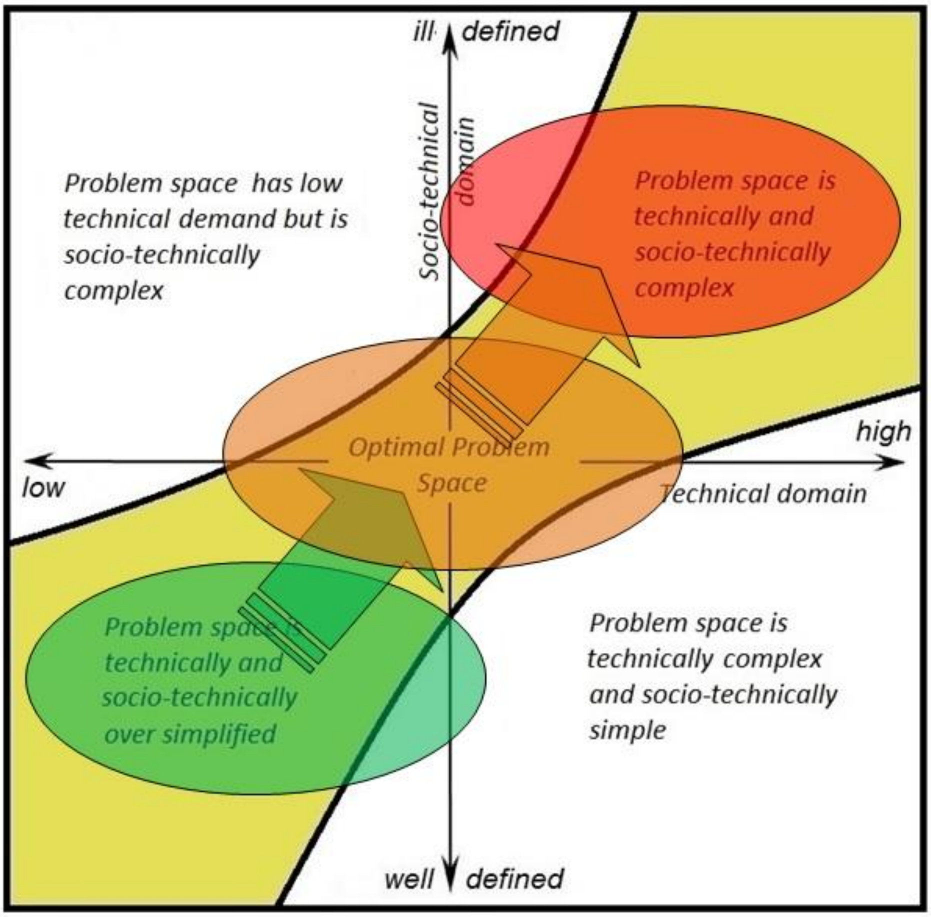

Fig 7. From Regular to Ill-defined Problem Spaces in the Weak Judgement in ALL Principle.

By way of example, where a project specification asks that learners submit functional systems analysis, product design specifications, kinematic analysis and Pugh matrices, the following assignments could require learners to use their experience in product design to include supporting evidence as they consider appropriate to the task justifying their choices and omissions. The intention being that they are importing learning from earlier work and making judgements about that knowledge in the context of defining the problem space for a new assignment. Gradually over the course of the undergraduate programme the learner should become more accomplished at exercising the judgements that define problem space and making professional judgements about the complexities and uncertainty of real life projects. An assessment instrument for QCF levels 4 to 6 is set out below.

QCF level 4

Aims:

Community of Practice - Learning about models for solving engineering product designs

Tools & Methods:

Providing a detailed project specification and assessing compliance.

Assessment Instrument:

1. Initial product assessment - identify needs, loadings and approximate costs [10%]
2. Function Analysis Systems Technique (FAST) Diagram [10%]
3. Quality Function Deployment (QFD) Diagram [10%]
4. Product Design Specification to BS7373 (PDS) [10%]
5. Initial concepts and concept selection (on an A3 poster) [10%]
6. Drawing package – assembly and detail drawing plus parts list, to BS8888 [20%]
7. Individual Log book & Portfolio of tutorial work [Individually assessed] [10%]

QCF level 5

Aims:

Community of Practice & Inquiry - Selecting and justifying models for solving engineering product designs

Tools & Methods;
Providing a partially detailed project specification and assessing the capacity to judge the necessity for particular types of evidence to support the design with compliance to some particular requirements.
Assessment Instrument:

1. Product development portfolio of evidence supporting your design to appropriate British Standards.* [60%]
2. Justification of your selection or omission of product design evidence [10%]
3. Discussion of Ergonomics, Health and Safety and Sustainability [10%]
4. Validation – stress calculations and FMEA [10%]
5. Individual Log book & Portfolio of tutorial work [Individually assessed] [10%]

* The anticipated outcome is that learners exercise the judgement to import analogies from the previous year's work about what they need to include as evidence. Learners in Case study 3 and 4 exhibited this behaviour albeit in implicit ways.

QCF level 6
Aims:
Community of Inquiry - Selecting and justifying models for solving engineering product designs in ill defined problem spaces.

Tools & Methods;
Providing an ill-defined project specification and assessing the capacity to define the problem space and judge the necessity for particular types of evidence to support the design.

Assessment Instrument:

1. Produce a design for a particular artefact. (An outline client product specification could be given to the learner or they could develop one by negotiation with the client)
2. Provide a design portfolio with supporting evidence to obtain buy in from an investor and the information necessary to manufacture the artefact. [70%]
3. Justification of your selection or omission of product design evidence. [30%]

Thus the programme structure and assessment over a period of 3 years gradually shifts from the prescriptive of ideal practice at QCF level 4 to the uncertainty and demands redolent of real world practice described by Trevelyan (2010) and the learner acquires skills in making judgements about practice.

In the 'Strong Judgement in ALL Principle' the proposed model is that the learner acquires by specific interventions awareness of judgement and cognitive bias and over the term of their programme of study acquire a criticality or scepticism of the judgements they make. All of the interventions in this research require learners to produce some kind of written output. Case study 1: 'Crash Investigation' requires the learners to develop a portfolio. Case study 2: 'Design and Construction of CNC Work-holding System' requires learners to maintain a team logbook. Case study 3, 'Mechanical Design & Sustainability Projects' requires learners to maintain individual logbooks and Case Study 4: 'Built Environment Design Integrated Project' assessable component includes the requirement to submit a project execution plan. The proposed assessment instruments do not necessarily involve additional work but a re-organisation of current practice to make reflective practices and peer review methods focus objectively on judgement and its assessment.

With the overall aim of developing judgement capacity to a professional level, the ALL interventions in the initial stages of a programme of study could introduce the learner to types of judgement and reasoning that is apparent in their own work. With this knowledge the learners can be constructively engaged in discussions about their judgements and discover how to record phenomena and judgements in their logbooks that provide a critical record of their working.

Progressively at later stages in their studies the learners should have acquired some degree of autonomy in identifying the types of judgement that they are making and be able to explain why they have used particular heuristic or rational judgements. In these stages the learner could also be introduced to common cognitive biases that effect reasoning and learn about the effects that they have particularly those that effect team work, project planning, commercial aspects and risk management.

By the end of the programme the learner is preparing to become a new professional entrant and by this point should be able to critically discuss their judgements and be able to make an assessment of the potential impacts of their judgements and especially the risks associated with heuristic judgements. By way of an example in project planning and costing, the potential to overestimate capacity or capability and underestimating time, risks and costs is inherent and even professionals are susceptible to the biases that cause this. The learner who has become critical of their judgements should be able to demonstrate that they have developed their judgement capacity to the point that they can identify the potential errors in reasoning and attempt to ameliorate them.

From the case studies, the cognitive load in making judgements is not strictly correlated with the complexity of the problem. Of course some judgements are more difficult than others, for example a judgement of discrimination is more easily exerted than a judgement of hypotheticality, however in the contexts of all of the case studies complex judgements of causality, hypotheticality and counterfactuality occur in relatively uncomplicated scenarios. From the case studies the incidence of heuristic judgements varies little with the complexity of the problem space but appears to be inversely correlated with the accumulated knowledge and experiences of the individuals. For example learners that are able to import reliable experiences and analogies appear to have acquired practices with more rational approaches to project solving irrespective of whether they understand the reasons or value of doing so.

The correctness or appropriateness of judgements is more evident in the actual reports of investigations of an event or the design of an artefact. Therefore the assessment instruments are focussed on assessing the learners development of knowledge of judgements and heuristics and adjusting for them rather than attempting to award marks for making correct or better judgements or making more complex judgements. The rationale for this approach is that judgements that are seen to be good in present circumstances may later be viewed differently when circumstances change. In addition, individuals are known to remain susceptible to heuristic biases and will still be prone to judgement errors even after years of self development. By focussing on developing knowledge of their judgements the learner is enabled to become more sceptical of their judgements and such an approach is more conducive to making professional judgements over time. An assessment instrument for this purpose is set out below.

1st year assessment instrument QCF level 4

Aims: Identifying types of judgement, rational and heuristic reasoning.

Tools and methods:

The learners maintain a virtual group logbook of tutorial and extra tutorial meetings. The log entry should confirm the date and who made the entries. The log should record all germane activities, propositions, decisions and actions. Each proposition, decision and action should be associated with the person originating it. The log is used to inform accountability and reflective practice. The learners will require initial tutorial input in identifying types of judgement and maintaining a sufficiently detailed logbook.

Assessable components: [20% of total project mark]

Individual Marks awarded for:

- Contribution to log maintenance. [10%]
- Judgements and decisions contributing to innovation, decision making and advancement of the project. [10%]

2nd year assessment instrument QCF level 5

Aims: Identifying types of judgement, rational and heuristic reasoning and in addition learn to identify cognitive biases and understand the effects of biases on their reasoning in context of the project.

Tools and methods:

The learners maintain a group logbook in the same manner as in year 1. In this stage learners should be introduced to the common biases that effect decision making in engineering. These are broadly the availability, anchoring, representativeness, confirmation and hindsight heuristics that affect decision making when making analogies in project planning and making risk assessments. The learners should be able to identify the instances in their project when these biases will exert pressures that affect their reasoning. The learners will require initial tutorial input in identifying types of cognitive bias and maintaining a sufficiently detailed logbook.

Assessable components: [20% of total project mark]

Individual Marks awarded for:

- Contribution to log maintenance. [5%]

- Identification of judgements and decisions contributing to innovation, decision making and advancement of the project. [10%]
- Correct identification of heuristics in the context of the project decisions. [5%]

3rd year assessment instrument QCF level 6
Aims: To be able to identify judgements and biases and apply ways of ameliorating the effects of judgements made under uncertainty.
Tools and methods:
The learners maintain a group logbook in the same manner as in years 1 and 2. By this stage the log book entries should identify judgements that have been made with uncertain or incomplete knowledge and the heuristics that may have affected their reasoning. The learners should also be in a position to indicate any procedures they have relied upon to cope with the uncertainty or the effects of heuristics on their reasoning. Learners should be relying more upon methods of calculations or regulatory criteria and data from reference classes to inform their decision making. In general learners should be able to state critically that their judgements are appropriate or that they are sceptical of the validity of their decisions.

Assessable components: [20% of total project mark]
Individual Marks awarded for:

- Identification of judgements and decisions contributing to innovation, decision making and advancement of the project. [5%]
- Correct identification of heuristics in the context of the project decisions. [5%]
- Identifying ameliorations, reasoning from data sources and showing criticality and or scepticism of decision making. [10%]

10.4 Proposals for Further Development and Research

A number of questions arise out of this research that may be considered for further research opportunities.

1. The assessment instruments in section 10.3.2 are based upon the proposition that learners can develop judgement capacity by becoming aware of factors that affect judgements and by ultimately acquiring a criticality and scepticism of judgements made particularly when knowledge is limited or uncertain. I will say that the

expectation that learners simply appear to become better at judgement without becoming sceptical of their judgements is unlikely because of the effects of biases. The findings indicate that learner judgement tends to be more complex in complex scenarios but the cognitive effort doesn't increase proportionately due to the predominance of heuristic judgements at all levels. The implication is that what is taken for good judgement in one project may be circumstantial particularly when knowledge is incomplete and uncertain. In a subsequent project the judgements may better or may be quite poor or even reckless. I am inclined to the opinion that assessing improvement simply by trying to assess the quality of judgements by outcome is potentially erroneous or impractical and learners will not necessarily become better at making judgements every time they intend and resolve a problem space. A longitudinal study of a group or several groups of students from the first year of an undergraduate programme up until the end of final year would provide a useful indication of the extent to which the proposed intervention (ref. sections 9.8.3 and 10.3.2) improves the capacity of the learner through implementation of the provisional model.

2. Significant numbers of learners in case studies 1, 3 and 4 were observed and also reported to display a reluctance for collaborative work. There does not appear to be any explicit mechanism for promoting team work other than insisting that the work is done as a team. In current practice peer reviews or peer assessments are used to account for individual contributions to team project work. This not only depends upon the philosophic integrity of the learners but also the unlikely case that they can provide accurate accounts of activity that are free from hindsight bias.
   An action research project could examine the effects of introducing a group log book in which all team members have to record in sufficient detail all team work proposals, decisions, actions and identify contributors. The research could consider two goals a) Does the requirement for the team to keep a logbook improve team collaboration? b) Does the logbook evidence provide a more objective indication of the relative contribution of the team members?

3. Problem space theory predicts that professional judgement capacity is in part framed in the ability of the professional to efficiently and accurately reduce problem spaces to manageable proportions. The consequences for ALL is that project specifications that are prescriptive with regard to assessment criteria frame the

problem space for the learner and in so doing implicitly guide learners to model answers and deplete opportunities to exercise this important part of professional development. A longitudinal study on the effects of reducing project specification detail at each level of an undergraduate programme would provide useful indications of optimal initial conditions in presentation of the problem. The questions the research should aim to cover are; a) Does the intervention actually improve the ability of the learners to reduce a problem space rapidly and correctly or not. b) Is the intervention deleterious viz do learners become worse at defining problem spaces because they need to rely on guidance. c) Does it just increase the learners' perception of improvement viz make them more confident but actually produce no effects at all?

4. In case studies 2 and 4 the learners were required to cost their project as if it were a real life commercial development. In addition the learners had to submit requests for information when they needed tutor support as if they were consulting an external expert with whom they agreed a cost for that assistance. This intervention exerted some effects on the capacity of the learners to make decisions. Learners that have to consider the effects of decisions on economic viability tend to delay requests for support and appear to work longer and with greater determination at a problem before seeking support. In some way the learners are compelled to more critical reasoning between the heuristic ease of acquiring expertise and the rationality of trying to solve the problem themselves. Additionally, making judgements about the effort and economies of a project introduce a whole range of judgements of hypotheticality that expose levels of confidence and optimism where a learner also needs to develop criticality and scepticism. I will say this is an important question since engineering projects have to be commercially viable and it would be of great value to know how the inclusion of cost considerations in a project affect reasoning. I propose that an action research project comparing two groups, one with a cost consideration intervention and another without intervention as a control group. First and second year engineering groups tend to be quite large and may provide a sample of sufficient size to detect an effect. The research could be extended thus; the subject group receiving the intervention could in a subsequent project have no cost considerations to see if the effect persists or whether it is transient and therefore dependent explicitly on its inclusion in every project specification.

5. Case study 2 ref. Section 6 pp 102, indicates the potential for learners to exercise judgements of counterfactuality and instrumentality when they have the opportunity to construct their designs. Case study 4 section 8 pp143, illustrates similar potential when learners use computer simulations. Having learning experiences that re-activate experiences and knowledge provides opportunities to confront previous knowledge states and judgements. The resulting disjunctures should make re-examination of earlier decisions compelling. Projects that do not incorporate these learning experiences have no opportunity to do so and decisions that defined the early problem space may go unchallenged or in hindsight be thought correct. The question is how do these three scenarios qualitatively differ? Will learners make more critical re-appraisals if they actually make their design or is a simulation as good? If there is a difference is this due to the actual physical activity of making something? I propose that the premise could be examined through a case study in which groups of learners could be compared where the same design could be simulated by one group of test subjects and physically constructed by another.

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Appendices

Appendix 1

SEFI 2014 42nd Annual Conference, Birmingham, UK

Activity Led Learning and Developing Professional Judgement Capacity in Undergraduate Learners.

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Appendix 2

Activity Led Learning Environments in Undergraduate and Apprenticeship Programmes

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Abstract:

Transversal Competences are considered to be key developmental goals in higher education in preparing students for employment. This paper proposes that the faculty of judgement is the principal common cognitive component in transversal competences and that Activity Led Learning (ALL) can be used in both undergraduate programmes and the specific work related learning environment of apprenticeships to develop judgement capacity. The programme of research studied two categories of learners, one was a 3rd year students on the BEng Aerospace Engineering programme at Coventry University UK and the other group, were BTEC level 3 apprentices employed by an engineering company in the north-east of England. Employing a phenomenological methodology, the activities, meetings and dialogues of both groups of learners were observed, recorded and analysed together with copies of their meeting records and logbooks. Analysis of the records indicate that the application and exercise of transversal skills is a significant feature of the learning experience in which learners exercise complex heuristic and rational judgements.

Keywords: engineering projects, activity led learning, judgement, transversal competencies

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Appendix 3

Designing Activity Led Learning to Promote the Development of Professional Judgement Capacity.

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Abstract

Providing learning environments in which students can exercise and improve their understanding of the judgements they make should enable them to produce consistently better solutions to problems in professional practice. This paper proposes that Activity Led Learning (ALL) environments can be constructed to compel learners to exercise judgement in complex realistic project scenarios in order to promote the development of judgement as a part of the progression from student to new professional entrant. A phenomenological study was made of a cohort of first year BEng Aerospace students throughout a project of ten weeks duration. The purpose of the study was to observe and examine the learners' experience of exercising judgement in an ALL environment in order to determine whether the learning environment can be constructed to promote the development of judgement capacity. In the project the students were randomly divided into small teams of five to six and tasked to investigate and deduce the cause of an air crash. In the phenomenological study, the students were observed, and written accounts of their dialogues and activities were made and analysed. It was found that the students exercised a range of complex rational and heuristic judgments to develop their conclusions. The findings suggest that the duration of a project and the way in which the information is presented, have an observable impact upon the way learners define a potential problem space and in consequence the types of judgement that they can exercise.

Keywords: engineering projects, activity led learning, judgement

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Appendix 4

The Consent Statement

Participant Reference Code:__________

	Please tick
I have read and understand the attached participant information sheet and by signing below I consent to participate in this study.	☐
I agree to be filmed/recorded as part of the research data collection method. I understand that only the researcher will see the video clips or listen to the sound recording (as applicable).	☐
I understand that my participation is entirely voluntary and I have the right to withdraw from the study at any time up until 14 days after participation and without giving a reason by contacting the researcher at:- igarashh@uni.coventry.ac.uk.	☐
I understand that in the event of my withdrawal any data pertaining to me individually will be destroyed but it will not be possible to extract my individual (anonymous) data from group observation records.	☐
I understand that all information will be treated in confidence and that I will not be identified from the information.	☐

Signed: ____________________________Print Name:__________________________

Researchers signature: ____________________ Print Name: ___________________

Witnesses signature: ________________________Print Name:

✂- -

The Consent Statement

Participant Reference Code:_________

	Please tick
I have read and understand the attached participant information sheet and by signing below I consent to participate in this study.	☐
I agree to be filmed/recorded as part of the research data collection method. I understand that only the researcher will see the video clips or listen to the sound recording (as applicable).	☐
I understand that my participation is entirely voluntary and I have the right to withdraw from the study at any time up until 14 days after participation and without giving a reason by contacting the researcher at:- igarashh@uni.coventry.ac.uk.	☐
I understand that in the event of my withdrawal any data pertaining to me individually will be destroyed but it will not be possible to extract my individual (anonymous) data from group observation records.	☐
I understand that all information will be treated in confidence and that I will not be identified from the information.	☐

Signed: ____________________________Print Name:__________________________

Researchers signature: ____________________ Print Name: ___________________

Witnesses signature: ________________________Print Name:

Appendix 5

Reflective Precis **Date:**

Group______________________________
Participant_________________

What decisions were made by you or your group in today's activity? Who made the most important decision and why do you think it was important? Which of the decisions made by the group did you disagree with and why? What alternative decisions were possible? Why were they not presented/accepted? What effective/appropriate solutions/actions will result from the decision?
Observed judgements < researchers use only > **id**entity (same, equal): **sim**ilarity (resemblance): **mem**bership (species, families): **dif**ference (discrimination, logical, conceptual, material, perception): **val**ue (more than less than): **com**position (part of /belongs to) : **div**ision (do parts have the properties of the whole): **rel**evance (fallacies of relevance): **inf**erence (inductive or deductive): **app**ropriateness, (fitness) : **cau**sality (causal proximity): **ana**logical**,** (? is to ? as ? is to): **fac**tual (sufficient evidence) **hyp**otheticality (consequences): **cou**nterfactual (hindsight): **pra**cticality (standard procedures): **ref**erence (comparison): **mea**surement **(**arbitrary scales)**:** **tra**nslation, (meaning in contexts): **ins**trumentality (means end adjustment): **Int**ention attribution: **NOTES:**

Appendix 6

Work Log **Group: <Group ID>**

Name of recorder: You MUST state who made this entry **Date: DD/MM/YY**

Details of work planned: *Time, tools, materials, operations, operators To be completed BEFORE machining operations*
Machine pump body blank to 100 x 70 x 43 Locating tools and instruments <name> Set up: clock vise to machine table using dial test indicator. secure vise <name> Secure work piece using vise, parallels and pinch bar. <name> Cutting <name/s> Checking work is cut to correct size ,name> Deburr and identify work piece Clean up workspace
Summary of actual operations completed: *Include <u>all variations</u> and reasons for changes*
Machined blank finished sizes were 100.01 x 69.98 x 42.5 *Took 20 minutes clocking in vise, lost total of 25 mins cutting time in setting up. Rotating vise to cut bevels took 25 minutes.* *Had to replace worn tips in face cutter. 15 mins*
Reflection and Analysis: *explaining your Judgments, decisions and actions.*
Was the planning correct, i.e. was anything unplanned for and how significant were the variations to plan? We didn't plan/calculate the angle setting for the vise in advance (cutting bevels). If we had done so we would have gained 20 minutes cutting time We didn't foresee the failure of the face cutter tips so we didn't have any to hand and lost time looking for replacements. Were the variations to plan the best decisions that could be made or where there better alternatives? Could have allocated the task of monitoring the progress and anticipating the need for tools and information. If there were alternatives what reasons can you give for not implementing them? There were no planned alternatives for this stage How well did your group function as a team on these tasks? As above, time could have been used more efficiently.
All work in progress, tools and instruments have been cleaned and safely stored. Tick to confirm □ Damaged or missing items have been reported. Tick to confirm □ All 'tear down' completed and machinery has been cleaned down. Tick to confirm □ Any incidents have been reported and documentation completed. Tick to confirm □

Appendix 7

Participant Briefing Sheet (Undergraduate)

Purposes
I am conducting research into the development of professional capacity in engineers. I am particularly interested in the way students develop professional capacity in making judgements about themselves and their work.

Why have I been asked to participate
You are enrolled as undergraduate students in one of the engineering departments at Coventry University. In this programme you will engage in various types of Activity Led Learning which is thought to be particularly relevant in developing engineering thinking i.e. projects and problem solving. The research in which I am asking you to participate will inform further development of Activity Led Learning and the development of judgement capacity which may be used to inform policy and understanding in engineering education.

Do I have to take part?
No. Participation is entirely voluntary. If you change your mind about taking part in the study you can withdraw at any point during the sessions and at any time up until the 31st July 2014. <u>You can withdraw by contacting me.</u> If you decide to withdraw any data will be destroyed and will not be used in the study. There are no consequences to withdrawing from the research. It is not possible to withdraw from a research study after the research results have been published or otherwise put in the public domain.

How do I contact you? by email at:- igarashh@uni.coventry.ac.uk

What does it involve?

- You will periodically be asked to write a very brief reflective precis about the types of decisions you have made in completing a project and what influenced those decisions.
- I will also observe the research participants working individually and in groups and record activities. The observations will be recorded either manually or where students have consented, by video.
- I will interview selected volunteer participants at stages throughout the programme.

Is this a lot of extra work?
No, the activities are quite brief. The reflective precis will take approximately 10mins to complete. The observations will be unobtrusive and the interviews will take no more than 30 mins at mutually convenient times.

Are there possible disadvantages and risks in taking part?
There are none

What are the possible benefits of taking part?
Participation will assist you in reflecting on your learning experiences and interacting with your tutor and your studies. It will guide you in thinking about the areas of professional development in which you may wish to seek help. Becoming familiar with your own professional development and how you provide evidence of development is useful in developing narratives for job interviews etc.

Will my taking part in this study be kept confidential?
Yes. Only I will have access to the raw data. All the consent forms will be stored in a separate, secure (locked) location from the raw data itself. You will only be identified on the score sheet by your participant number. The raw data from the research will be destroyed at the end of the research project. When the data has been entered into a computer file, your scores will only be associated with your code number and access to the file will be password protected.

What will happen to the results of the research study?
The results will be written up and presented as part of my doctoral research thesis. If the results are novel, they may also be presented at academic conferences and / or written up for publication in peer reviewed academic journals.

Appendix 8

Participant Briefing Sheet (Apprentice)

Purposes
I am conducting research into the development of professional competences in engineers. I am particularly interested in the way students develop professional capacity in making judgements about themselves and their work.

Why have I been asked to participate?
You are enrolled as apprentices on the [redacted] Apprenticeship + programme. In this programme you will engage in various types of Activity Led Learning which is thought to be particularly relevant in developing engineering thinking. I would like you to participate in a small piece of research to inform further development of Activity led learning methods and inform policy and understanding in engineering education.

Do I have to take part?
No. Participation is entirely voluntary. If you change your mind about taking part in the study you can withdraw at any point during the sessions and at any time up until 2 weeks after the end of the course. <u>You can withdraw by contacting me.</u> If you decide to withdraw any data will be destroyed and will not be used in the study. There are no consequences to withdrawing from the research. It is not possible to withdraw from a research study after the research results have been published or otherwise put in the public domain.

I can be contacted through the HR department at [redacted] or directly during the learning sessions.

What does it involve?

- I will also observe you working individually and in groups and record activities either manually or with your agreement by video.
- Each group will also maintain a log book of their work.
- I may wish to interview selected participants at stages throughout the programme

Is this a lot of extra work?
No, the activities are quite brief. The questionnaires will take approximately 20 mins to complete. Log books will be required as part of your normal learning experience.

Are there possible disadvantages and risks in taking part?
There are none

What are the possible benefits of taking part?
Participation will assist you in reflecting on your learning experiences and interacting with me (your tutor) and will guide you in thinking about the areas of your own professional development. Becoming familiar with your own professional development and how you provide evidence of development is useful in developing narratives for job interviews etc.

Will my taking part in this study be kept confidential?
Yes. Only I will have access to the raw data. All the consent forms will be stored in a separate, secure (locked) location from the raw data itself. You will only be identified on the score sheet by your participant number. The raw data from the research will be destroyed at the end of the research project. When the data has been entered into a computer file, your scores will only be associated with your code number and access to the file will be password protected.

What will happen to the results of the research study?
The results will be written up and presented as part of my doctoral research thesis. If the results are novel, they may also be presented at academic conferences and / or written up for publication in peer reviewed academic journals.

Appendix 9

103SE Coursework – Portfolio

Lecturer’s name	Mrs C Jones
Coursework Title or Number	Portfolio
Module Number	103SE
Participants	Individual
Required submission date	4th April 2014
Learning outcomes covered	1,2,3,4,5,6
Marking scheme and marking criteria	Included
Percentage of module mark	80%
Estimated effort (hours/words)	35 hours
Submission Details	Online Submission (2MB file size limit convert to PDF)

Introduction

To deserve a Bachelor of Engineering degree, a student needs to have a comprehensive understanding of practical engineering as well as a good academic grounding. In your Portfolio, you are tasked with showing your depth of practical understanding and appreciation by mapping the skills that you have learnt and reflected upon against the following criteria.

1. Plan and conduct engineering experiments safely, interpret the results obtained and record the results by way of logbook, and oral presentation.
2. Compare and interpret the theoretical and practical aspects of areas of aerospace engineering.
3. Employ basic manufacturing processes and recognise their capabilities.
4. Apply basic design skills to an engineering problem.
5. Produce and interpret sketches and formal engineering drawings.
6. Apply MATLAB to solve simple engineering problems.

You can use the resources on MOODLE, Internet, library, personal contacts and staff in the aerospace department at Coventry University to help inform your learning. Every external resource that you use to gain information has to be referenced in accordance with CU Harvard Referencing Style.

A guide to which can be found at: http://www.coventry.ac.uk/study-at-coventry/student-support/academic-support/centre-for-academic-writing/support-for-students/academic-writing-resources/cu-harvard-reference-style-guide/.

Evidence

You must show evidence of learning in your portfolio and this can include videos, images, text, bog information, links to websites, file downloads etc. but it must be clearly laid out and easy to read.

Laboratory Worksheets

During every lab there is a corresponding worksheet available on Moodle. You are required to print and use these during your exercise to take note of work carried out and your achievements. This work can be used as evidence of learning along with the associated quiz.

Quizzes

After your lab exercises you will be asked to complete a quiz on the tasks. Please read all materials provided for the tasks and you may bring these with you to your Quiz. For the timetable of these Quizzes please see the module guide for further information. The topics include aircraft control surface removal, flight simulation analysis, PLOC, helicopter control and PFCU. The marking of the Quizzes will be completed electronically; they will be a range of question styles including multiple choices, written, ordering and calculative questions. Please use the practice questions available to help you to prepare.

Presentations

Submitting your presentations in your portfolio is necessary to meet criteria 1. However you must also reflect upon your experience including the delivery of the oral communication challenges as well and the technical composition of the presentation and alignment to the six criteria.

Crash InvestigationPresentation

Your presentation has already been marked but it is expected that you use evidence from this presentation to reflect on how you have improved from your crash investigation presentation to the hydraulic actuator presentation. You may use your feedback from this report to help you.

Hydraulic Actuator Presentation

Your presentation should highlight content that you learnt throughout the module showing the development of a hydraulic system.

Your page limit is 10 pages/slides in this you should include:

1. Introduction to your system and the research you did
2. Technical Specification and regulations adhered to
3. SIMULINK Design
   a. Results
   b. Errors
   c. Schematic
4. Actuator
   a. Size inputs and how this was calculated
   b. One * 3rd orthographic technical drawing
5. Manufacture procedure of actuator components
6. Installation, maintenance and service requirements
7. Evolution of the design for the future including recycling and retiring of the product
8. Reference List

Presentation: The layout should be clear and easy to view with labeled units on graphs. It should all be referenced with CUHarvard References and in text citations.

Hints and Tips:
There are several areas that people make people enjoy a presentation and remember the experience these include:

- Clear verbal communication skills to the audience from all members with confidence
- Relevant materials are being used on the slides (no overcrowding of text)
- Clear to read and fully labeled images and graphs.
- Extra materials or uniqueness/something unexpected
- Time keeping; it’s not too short or too long.

Your presentation will be submitted online via the Moodle Link to check for misconduct.

Tools

Please use the appropriate Mahara Portfolio Building website which is linked to Moodle.
Example: http://cumahara.coventry.ac.uk/view/view.php?id=9649

Report Marking Matrix										
Mark Range	**Criteria**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
90-100%	The structure is clear and shows planning adhering to suitable regulations and the content covers all areas. It is correctly referenced and correct grammar is used. The interpretation of sketches and formal drawings is clear and precise. The produced drawings conform to BS8888 standards. The main areas of design are evident and MATLAB is used in a professional manor. Research is clearly evident and clearly presented in a professional manor. All manufacturing processes are clearly identified with professional direction.	12	12	12	12	12	12	12	8	8
80-90%	The structure is clear and shows planning adhering to regulations the content covers all areas. It is referenced and correct grammar is used. The interpretation of sketches and formal drawings is clear and evident. The produced drawings conform to BS8888 standards with minor errors. The main areas of design are evident and MATLAB information is clearly presented. Research is evident and covers all main areas of aircraft attachments with comparison and evaluation. All manufactured processes are identified with some directions.	10.8	10.8	10.8	10.8	10.8	10.8	10.8	7.2	7.2
70-80%	The structure is somewhat clear and shows planning and attempt at adhering to regulations the content covers all main topics. It is correctly referenced and correct grammar is used. The interpretation of sketches and formal drawings is evident. The produced drawings conform to BS8888 standards with minor errors. Some main areas of design are evident and MATLAB information is presented. Research is evident and identifies some areas of aircraft attachments with comparison and evaluation. All manufactured processes are identified with limited directions.	9.6	9.6	9.6	9.6	9.6	9.6	9.6	6.4	6.4
60-70%	There is some structure and shows some planning and attempt at adhering to regulations the content covers all main topics. It is incorrectly referenced and some minor grammatical errors exist. The interpretation of sketches and formal drawings is evident. The produced drawings conform to BS8888 standards with some critical errors. Some areas of design are	8.4	8.4	8.4	8.4	8.4	8.4	8.4	5.6	5.6

	evident and MATLAB information is presented with limited information. Some manufactured processes are identified with some directions.									
50-60%	The structure is not clear and shows little planning and is not adherent to regulations the content does not cover all main topics. It is not referenced correctly and some grammatical errors exist. The interpretation of sketches and formal drawings is minimal. The produced drawings conform to BS8888 standards with some major errors. Limited areas of design are evident and MATLAB information has many errors. Research is visible and identifies some areas of aircraft attachments with some evaluation. Research is visible and identifies some areas of aircraft attachments with some comparison and evaluation. A manufacturing process is identified with some directions.	7.2	7.2	7.2	7.2	7.2	7.2	7.2	4.8	4.8
40-50%	The structure is not clear shows minor planning is not adherent to regulations and the content does not cover all main topics. It is not referenced and grammatical errors exist. The interpretation of sketches and formal drawings is not seen. The produced drawings do not conform to BS8888 standards. Minimal areas of design are evident and MATLAB information is missing. Research is minimal and identifies some areas of aircraft attachments. A manufacturing process is identified with no directions.	6	6	6	6	6	6	6	4	4
30-40%	Major problems exist in the research, MATLAB coding and report investigation is not completed. There are major errors and or omissions. The report highlights a poor understanding of the underlying theory.	4.8	4.8	4.8	4.8	4.8	4.8	4.8	3.2	3.2
20-30%	There are critical errors and or omissions in the final work that makes its interpretation difficult.	3.6	3.6	3.6	3.6	3.6	3.6	3.6	2.4	2.4
10-20%	The work is virtually indecipherable.	2.4	2.4	2.4	2.4	2.4	2.4	2.4	1.6	1.6
0-10%	Virtually nothing has been achieved.	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.8	0.8

Crash Scenario. For TUTOR (STAFF) EYES ONLY | 2013

1. Aircraft A320 takes off, shortly after take off, on climb out, aircraft has to make a sharp manoeuvre to avoid collision (NEAR MISS). This sudden manoeuvre causes aircraft to overstress and wing failure (PORT or STARBOARD?). Aircraft looses wing, aircraft crashes.

2. Other Aircraft (Harrier) lands safely (Note choice of words ‘safely’. Damage??? No damage as aircraft didn’t hit.

3. A320 is an old one series 200 (211).

4. Weather report: no wind, but poor visibility due to fog. See separate METAR/TAF

5. Bird Unit report = See Separate Report.

6. Students work through the investigation, with standard information released drip feed, other on request. See table for details:

Information	**Given or on request**	**When Given**	**Completed /Finalised**
Initial Details	Given	Start	
Monday 30th Sep 1300 hrs & 1500hrs.Brief from MD. Students produce a press release by Tuesday 1st October (Tutorial periods MFG15&16) Should contain, Aircraft Type, Destination, Departure airfield, Take off time, Payload/cargo, Flight safety record/history, Fatalities, Crews families have not been informed but are being informed now, The above information to be given by staff (me) at front of class, students will take notes and will get a chance to ask questions after brief/statement from staff.			
MET report	Given on Tuesday 1st Oct	After production of press statement by students	
Eye witness accounts **one only** per group	Given on Tuesday 1st Oct	After production of press statement by students	
Remaining Eye witness accounts	Given	Given on Thur 3rd Oct	
Technical Log	Given	Given on Thur 3rd Oct	
ATC Report/statement inc Bird unit report, Terrorist intel.	Given	After above at TIME?	
Week Two			
Technical log Quiz?	Takes place	Tuesday 8th Oct	MFG15/16 9am & 10am
Week Three			
(Mahara Intro)	Takes place	Tuesday 15th Oct	MFG15/16 9am & 10am
Aircraft Trade Diary	Given	Tuesday 15th Oct	MFG15/16 9am & 10am
Week Four			
Updated Press release Video Presentation duration max 3 minutes	Takes place	Tuesday 22nd Oct	MFG15/16 9am & 10am
Week Five			
CVR and Data Trace (MATLAB INTRO)	Given	Tuesday 29th Oct	MFG15/16 9am & 10am
Week Six (5th Nov)			
Review of Information e.g. the CVR & ADR transcripts, Trade Diary, Tech Log. Chronologically account of events. (What happened and when.) Indication of initial thoughts of Probable causes.	Hand in by end of session 10:00 or 11:00 hrs	Tuesday 5th Nov	MFG15/16 9am & 10am
Week Seven			
Continue working during Tutorial		Tuesday 12th Nov	MFG15/16

			9am & 10am
Week Eight			
Update on investigation, supporting evidence including graphs to prove/ disprove your findings. Also begin prepping for presentation. (Upload NLT 29th Nov)	Upload on Mahara	Tuesday 19th Nov	MFG15/16 9am & 10am
Week Nine			
Work on Presentation	Upload on Mahara NLT 29th Nov.	Tuesday 26th Nov	MFG15/16 9am & 10am
Info on Request			
Airworthiness Directive	Request Only	Post TLP	
Air Prox Report	Request Only	Post TLP	
Interview with other aircraft Pilot	Request Only	Post TLP	
Extra TLP Supp servicing sheets	Request Only	Post TLP	
Crew Details	Request Only	Post TLP	
Students produce graphs to support their findings with there recommendations and probable cause of the accident. Presented as a video presentation/ or normal presentation/ flip charts etc???			

Initial issue of Info including TLP contains:

1. Leading Particulars (TLB)
2. CAT 2 Status Sheet (TLB)
3. Registration Document (TLB)
4. Mod Record (TLB)
5. AD & SIB Info (TLB)
6. TLP (Fight Log and Maint Record)
7. Air Operators Certificate
8. Approval Cert (Part M & Part 145)
9. TCDS Extract for Aircraft Type
10.
11.
12.
13.
14. Document Control Sheet (TLB)*
15. Acceptable Deferred Defects (TLB)*
16. Cabin Deffered Defects (TLB)*
17. ADD Control Sheet (TLB)*
18. Cabib DD Control Sheet (TLB)*
19. Line Station Requirements (TLB)*
20. LSR Control Sheet (TLB)*

* Not developed at this Time 13 Sept 2013.

Appendix 10

Case Study 2: Design and Construction of a CNC Work-holding System

Each team is to operate as a small enterprise of consultant engineers who have been commissioned to design, draught and construct a work-holding system for the CNC machining of the component shown in the drawings titled Bonnet Guide t33210-02-3. The client has provided drawings of the component and a brief specification of their requirements.

1. *Provide sufficient project planning, costings and design information to enable your client to approve the development for drawing by presentation by the deadline 20th December 2013*

2. *Provide a set of CAD drawings to enable you to be able to machine the components of your work-holding system ready for assembly by the deadline 7th February 2014.*

3. *Machine, assemble and test your work holding system by the deadline 13 June 2014.*

Additional information

1. *Maintain a detailed work log of your project - it contributes significantly to your assessment.*
2. *The completed work holding system should meet the specification or you must justify any agreed variation.*
3. *Your final presentation will involve a ‘defence’ of your solution to a panel. You will be required to present your design and completed fixture in a final presentation. Your whole design and its merits and how it meets the specification should be presented as to the client and your project management as if to your own company directors.*

4. *If you require expert input from 'a consultant' you will have to submit a 'request for information' (RFI). The cost of the consultants input/knowledge comes out of your project profits by agreement.*
5. *You are to consider your work valuable and protected commercial property and you may not collaborate with other teams*
6. *If you do not meet deadlines you will be liable for a penalty of 10% of your costed profits for each over run.*

Your team work, project management, design defence and evaluation, and the most appropriate technical solution – v – cost are the examination criteria.

The Client's Specification.

A palette work holding system for the attached drawing ref. T33210-02-3 'Bonnet Guide'.

Materials: *machinable through-hardening alloy steel, that can be surface hardened to create components with enhanced wear resistance.*

Size: *ref. drawing, work holding palette to secure the work piece for machining, size not to exceed 200mm x 150mm. Vise block/bolster may be any convenient size.*

Mass: *ref. safe manual handling regulations. Combined weight of pallet and work piece not to exceed 12kgms.*

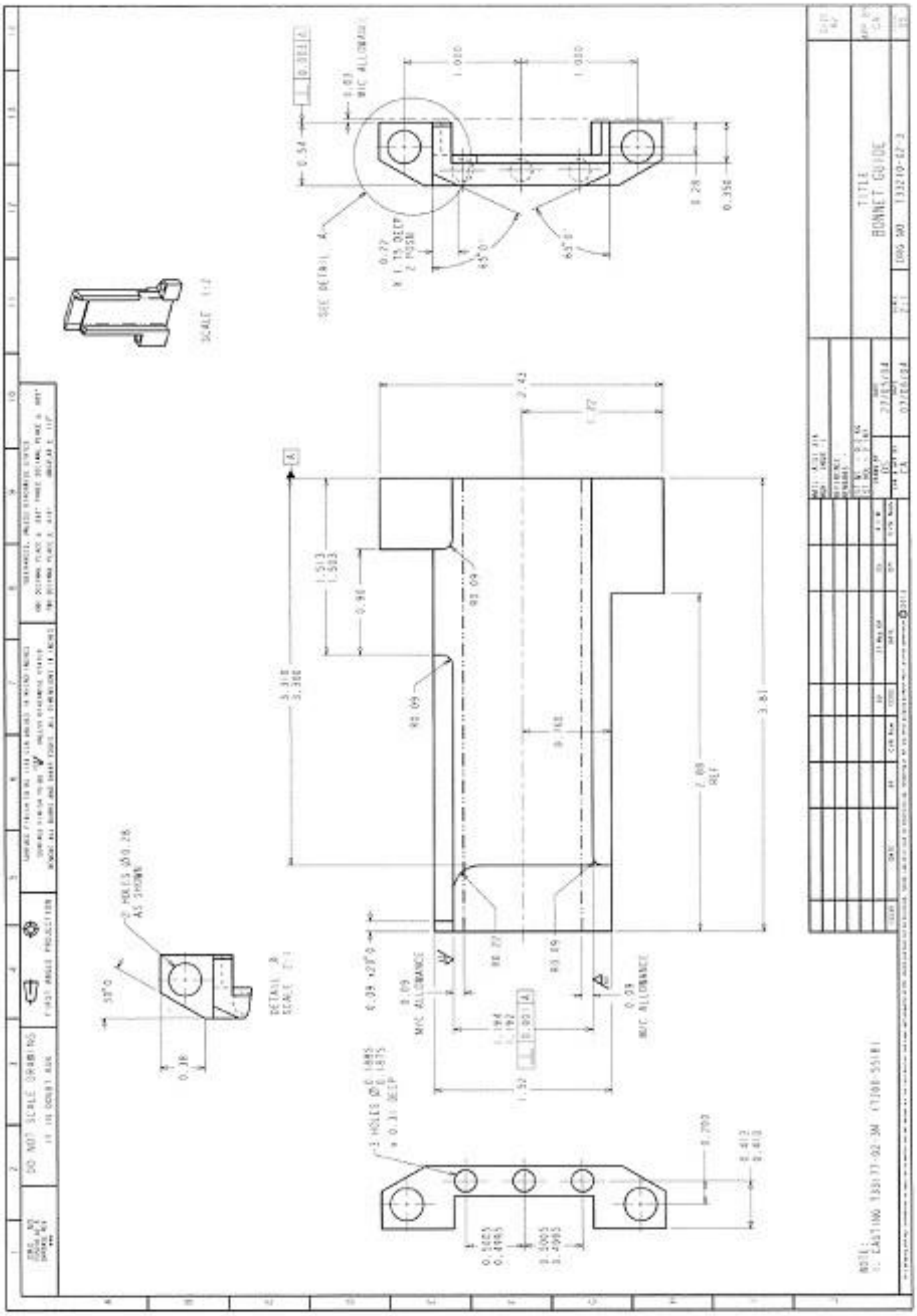
Kinematics: *Manual fast lock/release mechanism, hand operating force not to exceed 29.5ft lb (40Nm). Locked pallet must be rigid and secure.*

Power: *Manually lifted and locked/released.*

Cycle time: *Mount, lock/release dismount time under 6 seconds.*

Signals: *Identify loading orientation, full lock/release & direction. Include a Poka-Yoke system for loading error elimination.*

Bonnet Guide Drawing reference t33210-02-3



Appendix 11

209MAE Design & Sustainability Assignment CAD-CAM 2013/14

1. Aim

This coursework aims to develop a number of key capabilities required in the mechanical/automotive product innovation process. Specifically these include: creativity, management, experimental methods, analysis and synthesis, and the application of information technology tools. The aim will be met by tackling a product innovation project based on satisfying a requirement associated with a mechanical application.

2. Introduction

There is a requirement to convert a rotary input motion into a linear output motion.

3. Objectives

A concept should be proposed to satisfy the customer requirements, which includes the following key points -

The solution must be a mechanism-based assembly.

The solution must not have the rotary input directly driving the linear output.

The solution must be assembled to a generic base plate.

The solution should have the human interface outside the boundary of the base plate.

Final design proposals should demonstrate clear understanding of the requirement to be satisfied, an analysis of the problem and its applications, consideration of force, materials, manufacture & cost.

2D drawings of the base plate will be available on the 209MAE Moodle page.

4. Task

Working in groups you are required to use a series of engineering techniques to develop and systematically select a concept proposal to satisfy the needs of your client. You will use the base plate design provided as the fundamental starting point; a physical example will be available on the Lower Ground floor in the ECB.

Your solution should be innovative and not simply a copy or development of a current solution.

5. Deliverables

Your submission, to be submitted by Turnitin, should include –

- All output presented in the form of a Final Report, which should also include

    - Component functionality, strength, material, manufacture and cost.
    - customer requirements
    - technological advancements in the product area
    - resource requirement of the product
    - Statement of requirements
    - Evidence of consideration of sustainability

- 3D models of your components and a Fully Assembly model
- 2D drawings to BS8888, including a Bill of Materials
- FAST diagram
- Free Body Diagrams and appropriate engineering analysis in consideration of engineering requirements
- Detail and output from your concept generation activities
- Detail and justification for choice of solution
- Individual logbook
- Delcam program for manufacturing your components

6. Organisation and Timing

- The work will be carried out as a group of 4. The hand-in date is **The hand-in date is 1600 hrs on Monday 10th January 2014.** A single group report is to be submitted via Turnitin on the 209MAE Moodle page.
- The final report should be presented to the format set out in the report writing lecture notes posted on the module guide.

Late submissions will be awarded a zero mark.

7. Assessment

This assignment accounts for **40%** of your module mark. Each group should compile & submit **one** report document using the Turnitin link on the 209MAE moodle page by **1600 hrs on Monday 10th January 2014.**

Marks will be awarded to each of the following,

- Final Report [15%]
- 3D models of your components and a Fully Assembly model [15%]
- 2D drawings to BS8888, including a Bill of Materials [15%]
- FAST diagram [5%]

- Free Body Diagrams and appropriate engineering analysis in consideration of engineering requirements [10%]
- Detail & Justification for choice of solution [10%]
- Detail and output from your systematic concept selection activities [10%]
- Individual logbook & Portfolio of tutorial work [Individually assessed] [10%]
- Delcam program for manufacturing your components [Individually assessed] [10%]

8. Individual Mark

You will gain an individual mark for this assignment dependent on the proportion of work/effort you contribute. This will be determined objectively by factors such as peer assessment, individual logbook, attendance at meetings, displaying initiative and creativity, reliability, work rate and contribution to the final report.

Submissions not containing a meaningful discussion section are unlikely to attract high marks.

9. Notes:

The Report

The report should comprise of a referenced, clearly written, sequential output which should address all elements expected for assessment (see previous section). In particular, concept sketches should be of good quality and should be accompanied by labels, descriptive text and a consideration of the advantages and disadvantages of each concept. At least **THREE** concepts should be considered in this report. The report should also contain a discussion, which should consider and discuss all elements of the groups work leading to the final concept selection**.**

- Individual work should be identified with a name at the top of each page.

- Guidelines for report writing for engineers can be found on your Moodle 2 programme web.

Appendix 12

Faculty of Engineering and Computing

209MAE Design & Sustainability
Design Assignment 2013/14

Task for Mechanical Students only

10. Aim

This coursework aims to develop a number of key capabilities required in the product innovation process. Specifically these include: creativity, management, experimental methods, analysis and synthesis, and the application of information technology tools. The aim will be met by tackling a product innovation project based on satisfying a requirement associated with an industrial application.

11. Introduction to Task

A supplier of lift systems want to explore the possibility of introducing a new product into the market capable of lifting and removing an engine and gear box from a motor vehicle engine compartment. Current systems are large and clumsy. The new system should be easy to use (ergonomic) and 'fold-away' or dismantle for storage when not in use. It should also be a sustainable solution.

12. Objectives

The solution must be a fabricated system utilising standard section materials and identifiable proprietary items. The solution must be capable of raising and clearly removing a load with an appropriate factor of safety. Final design proposals should comply with all identified needs. Drawings can be produced by CAD or by hand.

13. Task

Working in groups of 4, you are required to use a series of design tools and techniques to develop and systematically select a concept proposal to satisfy the needs of your client. You will use the Robin Hood kit car, located in the ECB lower ground floor, as your reference vehicle. Measurement requirements should relate to this vehicle, including clearences, centres of gravity and lifting points. The mass of the engine is 160kg and the gearbox 33kg.

Your solution should be innovative and not simply a copy or development of a current solution. It should not contact the vehicle other than the engine itself.

Consideration should be given to balance and the anchoring of the system and how the forces are managed when the system is in operation. The solution should be safe & fit for use by one able-bodied person. The client requires 500 units to be manufactured.

14. Deliverables

Your submission, to be submitted by Turnitin, should include –

- An initial needs analysis
- FAST diagram
- Competitor analysis and QFD diagram
- Product Design Specification to BS7373
- Detail of two alternative concepts with detail of form, materials, manufacture and cost
- A systematic concept selection
- Free Body Diagrams and appropriate engineering analysis of chosen concept to include load and stress calculations for all stressed components.
- Assembly drawing and parts list
- Detail drawings of all original parts
- Failure mode and Effect Analysis
- Validation to include a discussion of ethical issues, product sustainability, safety and compliance
- Individual logbook

15. Assessment

This assignment accounts for **60%** of your module mark. Each group should submit **one** report using Turnitin by **1600 hrs on Friday 4th April 2014**. The final report should be presented to the format set out in the report writing lecture notes posted on the module guide.

Marks will be awarded to each of the following,

- Initial product assessment - identify needs, loadings and approximate costs [10%]
- Function Analysis Systems Technique (FAST) Diagram [10%]
- Quality Function Deployment (QFD) Diagram [10%]
- Product Design Specification to BS7373 (PDS) [10%]
- Initial concepts and concept selection (on an A3 poster) [10%]
- Drawing package – assembly and detail drawing plus parts list, to BS8888 [20%]
- Discussion of Ergonomics, Health and Safety and Sustainability [10%]

- Validation – stress calculations and FMEA [10%]
- Individual Log book & Portfolio of tutorial work [Individually assessed] [10%]

Submissions should contain a title page, summary, content page, introduction, discussion and references.

16. Individual Mark

You will gain an individual mark for this assignment dependent on the proportion of work/effort you contribute. This will be determined objectively by factors such as peer assessment, individual logbook, attendance at meetings, displaying initiative and creativity, reliability, work rate and contribution to the final report.

Appendix 13

Coventry University

The Department of Civil Engineering, Architecture and Building

300CAB Integrated Project

333BE Civil Engineering Design & 364BE Integrated Project – (Full time only)
Detailed Assignment Brief (2013/2014)

Assessment and Project Tasks

Summary of Brief

Overriding Company Directives

During all stages of the project the work must be equally and responsibly divided amongst company members.

Although the work will be carried out on an individual basis, the company must demonstrate it has been carried out in a coherent and co-ordinated manner.

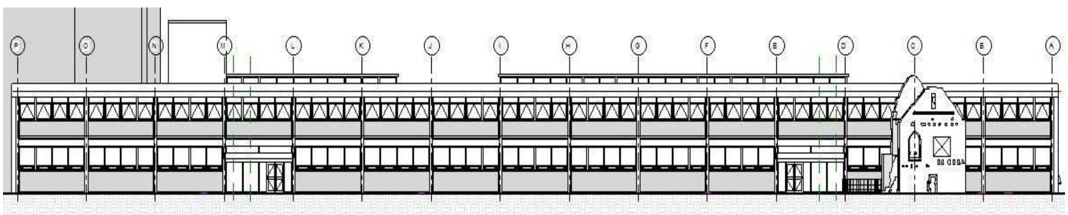
It is important to emphasise the need for all group members to collate and organise all of the information in an interoperable BIM like manner in order to make the progression onto later stages easier. All data will need to be collated in one clear package.

The company will need to demonstrate that they have communicated and worked together effectively throughout in a collaborative and integrated manner.

REMEMBER, you must report your major decisions in your meeting minutes

There will be FOUR main components/threads to this project;

- **The BIM Collaboration and Coordination**
- **The Sustainability and Build Strategy**
- **The Architectural Design**
- **The Structural Design**



1. Stage 1- Preparation

Weeks 1 – 4 (4 weeks). (Group mark 10%)

As soon as the companies are formed each group should then proceed to complete the 'Project Execution Plan' (PEP). This PEP document aims to help you collaborate and communicate efficiently as part of a company. These are invaluable skills which you will draw upon often when in industry.

The Template PEP document has been laid out in such a way as to make your life easier and in consequence make for a more efficient and harmonious group project.

It aims to help you gain an understanding of the 'Information' aspect of BIM.

2. Stage 2- Concept Design

Weeks 5 – 10 (6 weeks). Formative feedback and presentation

The Company shall prepare a preliminary design proposal which will included the preliminary Architectural and Structural layouts, including wall, column and support beam positions, sustainability strategy, surveys and cost. The company shall explain reasons behind the choice of each scheme and the major differences between each in at the end of stage presentation.

All company members should be involved in developing the design. Within the timetable of your allocated meeting, time will be set aside to discuss and develop the design as a company with all members involved and inputting development ideas.

You should work in the designated project session by discussing ideas and developing a well thought out solution for the client's needs.

At the end of this phase all groups will be expected to present their design progress for an intermediary review presentation. Formative feedback will be given on the progress of the model and design whilst a summative grade will be given for the presentation.

Companies need to ensure that a basic 3D model is created and ready for Stage 3 to enable the BIM analysis to take place. The model should be of sufficient detail to be analysed, it does not however have to be a final polished version. The idea is for the BIM analysis to inform changes required which can be implemented into your final developed design at stage 4.

Formative peer assessment

3. Stage 3 – BIM Analysis and Interrogation

Weeks 11 – 15 (5 weeks). (Group mark 25%)

In this section groups will be tasked with collating and inputting all of the gathered design data and project information into a BIM design package.

This stage should be completed by all group members. It is imperative that all group members collaborate and work closely together to ensure that all of the data is collated and inputted into the design package as a company. This process aims to ensure that the lead 'designer' or 'BIM Coordinator' does not have the sole responsibility for collating a mass of information on their own. Each disciplines expertise will be required and each company member should be present at data collation stage to ensure that the correct information is inputted into the design package efficiently and accurately. This is a company task!

In this section groups will be tasked with interrogating and analysing the models and data that is associated with the model using varying techniques. Analysis and data take-offs should take place along with other specified model interrogation.

Each design package should be presented as outlined in the detailed brief in a professional and efficient format. Companies need to demonstrate that the project has been completed in a collaborative and integrated manner.

As you progress or tasks all of the design information needs to be collated in an organised manner into an electronic data source to create an efficient and integrated design package.

A report should be compiled by the BIM coordinator assessing the company's experiences in regards to collaboration and integration processes, with particular focus on the BIM processes. All company members should contribute to the report. See detailed notes for further guidance.

The analysis and data gathered from this stage should be used to inform the developed design stage tasks. There are multiple tools and processes within BIM that enable the user to inform the decision making processes behind a project.

4. Stage 4 - Developed Design

Weeks 16 – 20 (5 weeks) (Individual mark 50%)

In this section of the project you will develop the preferred preliminary design and progress onto confirming the design proposal and submit parts of a full tender submission for the project responding to the feedback received from stage 2 and the BIM analysis carried out at stage 3.

Once again it's important to emphasise the need for all group members to collate and organise all of the information in an interoperable BIM like manner in order to make the progression onto later stages easier. All data will need to be collated in one clear package.

Each design package should be presented as outlined in the detailed brief in a professional and efficient format. Companies need to demonstrate that the project has been completed in a collaborative and integrated manner.

Full submission of the current Stage 4 progress will take place. Full plans and the accompanying documentation should be submitted. All sections of the work bound together in a bound submission. Summative feedback will be given.

Additional to this all of the design information needs to be collated into an electronic data source in an efficient and integrated design package as specified in the detailed brief.

It's important that companies listen to the feedback given and act upon it accordingly; the feedback aims at giving companies a chance to improve their designs as per the clients wishes.

5. Stage 5- Presentation of Final Design Package

Weeks 21 – 24 (weeks). (Group mark 15%)

Companies should present their final design package in a professional and well prepared manner. It is down to the company to 'sell' their projects to the client representatives. As a company you should allocate the responsibilities of this stage amongst you as per your own deliberation. The best company will work together to ensure that the best possible presentation package can be delivered to the client in an attractive and visually appealing format.

Project Peer Assessment

A peer/self assessment scheme will be used during the module called WEB-PA. Each student will need to assess both themselves and the other members of their company based on their judgement of the contribution and effort made by each member. Failure to engage with this process will result in strict penalties being applied.

This assessment will form the basis of reflection regarding teamwork skills within the project.

As a result of the peer and self assessment process, each student will be awarded an individual teamwork mark. This individual teamwork mark is based on the final company mark moderated by peer/self assessment for each phase, and accounts for 50% of the individual's grade for each phase. The remaining 50% for each phase is achieved from the individual's technical grade awarded for completion of tasks in stage 2 & 4.

Detailed Breakdown of Brief

1. Stage 1- Preparation

Weeks 1 – 4 (4 weeks). (Group mark 10%)

1.1. Poster/Speed Dating Presentation

(Module team member with responsibility – Steve)

One A3 company poster advertising the company skills with a view of attracting offers from opposite companies.

Submission of Task 1.1

Pin-up by 4.00pm of **week 2 (7th October 2013)**. Posters will be submitted as part of **stage 1 tasks**

1.2. Project Execution Plan (PEP)

BIM Co-ordinator Guidance

The Project BIM Coordinator will be the overall BIM coordinator for the project and take the lead on the Project Execution Plan task.

The Project BIM Coordinator will be responsible for coordinating and reporting clashes and issues that may occur in the design aspects and research. It is not the job of the BIM Coordinator to resolve them. The resolution of issues will need to be addressed by all companies members involved with that issue.

Multi-disciplinary co-ordination with BIM is essential for a successful project.

Responsibilities will include;

- **Develop, implement and maintain the BIM Project Execution Plan (PEP)**
- Preparing the document for submission
- Ensuring that all 3D models are on track ready for the submission deadlines.
- Interdisciplinary BIM co-ordination
- Coordination task content Creation
- Record (if necessary) and monitor shared data and relationships between models e.g. grids, floor levels, shared project coordinates.
- Identify and agree any co-located or shared technical infrastructure needs, software package interoperability requirements and standards to be used by each company member to deliver BIM project.

As soon as the companies are formed each group should then proceed to complete the 'Project Execution Plan' (PEP) lead by the companies BIM Coordinator.

Submission of Task 1.2

i. Develop and produce the PEP document, submit hard and electronic copy of PEP.

2. Stage 2- Concept Design

Weeks 5 – 10 (6 weeks). Formative feedback and presentation

Overriding Advice and Prerequisites;

You may begin working in a 2D design environment but take note that you will be asked to produce a 3D design models of your buildings and structures as part of in the later tasks. It is up to you whether you want to use 2D and 3D software or just 3D software at this stage.

You may find it more efficient use of your time to pre-empt the later tasks and begin working in a 3D design environment from the outset; this is a company design choice which you will have to discuss in early meetings!

Use the PEP document to record your decisions and agreements on company protocols. Take care to continually amend the PEP document as and when needed with updates on design and working protocol decisions. The PEP document will be submitted for review at the end of each Stage.

2.1. BIM Co-ordinator Task

The Project BIM Coordinator will be the overall BIM coordinator for the project. At each stage the BIM coordinator should ensure that all of the documents are up to date and correct.

The Project BIM Coordinator will be responsible for coordinating and reporting clashes and issues that may occur in the design aspects and research. It is not the job of the BIM Coordinator to resolve them. The resolution of issues will need to be addressed by all company members involved with that issue.

Multi-disciplinary co-ordination with BIM is essential for a successful project.

Responsibilities will include;

- Develop, implement and maintain the BIM Project Execution Plan (PEP)
- Preparing the document for submission

- Ensuring that all 3D models are on track ready for the submission deadlines.
- Interdisciplinary BIM co-ordination
- Coordination task content Creation
- Record and monitor shared data and relationships between models e.g. grids, floor levels, shared project coordinates.
- Identify and agree any co-located or shared technical infrastructure needs, software package interoperability requirements and standards to be used by each company member to deliver BIM project.

Submission criteria for 2.1

i. Continue to develop and compile the PEP document
ii. Continue to maintain the BIM coordination of the project
iii. Assess the progress that is being made in regards to BIM, compile a short report outlining any issues or positives that the company has experienced while attempting to follow BIM practices and processes. (300-500 words)

2.2. Sustainability and Build Strategy

2.2.1. Sustainable Strategy desktop Study

(Module team member with responsibility – Abdullahi)

The findings of the sustainability strategy should continually influence the actual physical design throughout the stages of the project. You will be required to show and provide evidence within **stage 3** of how you have integrated your desktop study into the overall project and design. The research and the design should be cohesive in nature.

To complete this task you will need to;

- Carry out a desktop study researching possible techniques and strategies for improving the energy and environmental performance of buildings relative to achieving the BREEAM rating specified in the client requirements.
- A site survey of factors influencing the energy and environmental performance of your refurbishment solution and extension design;

Submission criteria for 2.2.1

i. Sustainability thread- A draft report should be created carrying out a background literature review of the best practices to achieve a low impact design. The findings of the report will be presented during the project review.

2.2.2. Survey, Specification and Costs

(Module team members with responsibility – Steve/Martin)

At this stage you will be required to carry out various surveying objectives which should then be used to present you findings within the review presentation. Any finding within these objectives should influence directly into the design and sustainability thread. Objectives which you should aim to achieve produce documents for include;

Submission criteria for 2.2.2

1. Building Survey report which includes a desk study with site investigation to identify existing services, constraints, and environmental features that may influence the project.
2. Calculate an approximate expenditure from the cost per m2 of the gross floor area. The use of superficial costing is appropriate within this initial stage. Identify key materials or products to be used.

2.3. Architectural Design

Two company members will head up the architectural design aspect of the project and work as the 'architectural design team'

(Module team member with responsibility – Main Design Process– Heather, Technical Output - Danny)

1. A preliminary set of Architectural drawings showing ideas to be presented to the client to secure their approval.
2. 3D Digital Model on BIM capable software;

   You may begin working in a 2D design environment but take note that you will be need to produce a 3D BIM* design model of your building as part of this stage. Companies need to ensure that a basic 3D model is created and ready for Stage 3 to enable the BIM analysis to take place.

   The model should be of sufficient detail to be analysed in stage 3, it does not however have to be a final polished version. The idea is for the BIM analysis to inform changes required which can be implemented into your final developed design at stage 4.

   You may find it more efficient use of your time to pre-empt this task and begin working in 3D from the outset, this is a company design choice which you will have to discuss in early meetings! Just be aware that it may be counterproductive to work in both 2D and 3D platforms.

   Tutorials will be provided to assist you in this process.

3. It's important to note that the architectural design team will have to continually collaborate and communicate with the sustainability and structural design team to ensure that the project is integrated at all stages.

***Choice of Software**

Company's may use other BIM software other than REVIT but they must be aware of certain factors;

- Online video tutorials will be provided on REVIT which takes you through the software from the beginning
- The decision has to be made as a group.
- The software must have full current BIM capabilities such as REVIT, Graphisoft, Bentley, RhinoBIM etc.
- The software must have free viewer access capabilities so markers can moderate and assess the model without the need to purchase licences or If you can successfully export your model via IFC to REVIT for assessment purposes then this is also a valid option.

- You should review all the requirements of the project before making any decision and assess whether you will be able to complete all the required tasks in your desired software.
- The downside is that we will not be able to ‘hold your hand’ outside of REVIT software in regards to tutorials and assistance, so be sure you have the required expertise within the company to do all the work!

Submission criteria for 2.3

- A site location plan (1:500)
- Site layout including the position and size of building (1:200)
- Architectural draft layout plans of all floors (1:50)
- Elevations indicating the external appearance of the building (1:50)
- 2 Sections (1:50)
- A 3-D illustration showing the massing of the project
- The concept stage 3D digital BIM model.
- You should also include bullet point explanations of why parts of the existing building have been removed or altered.

2.4. Structural Design

Two Company members will head up the structural design aspect of the project and work as the ‘Structural Design Team’

(Module team member with responsibility – Structural Design Process - Alfred, Technical Output - Danny)

You may begin working in a 2D design environment but take note that you will be need to produce a 3D REVIT* design of your structure which will be merged with the Architectural model in stage 3 for analysis using IFC exports. So it is up to you whether you want to use 2D and 3D software or just 3D software. You may find it more efficient use of your time to pre-empt this task and begin working in 3D from the outset, this is a company design choice, which you will have to discuss in early meetings! Just be aware that it may be counterproductive to work in both 2D and 3D platforms

Tutorials will be provided to assist you in this process.

***Choice of Software**

Companies may use other BIM software other than REVIT/AutoCAD but they must be aware of certain factors;

- The decision has to be made as a group.
- The software must have full current BIM capabilities such as REVIT or Bentley etc.
- The software must have free viewer access capabilities so markers can moderate and assess the model without the need to purchase licences or If you can successfully export your model via IFC to REVIT for assessment purposes then this is also a valid option.
- You should review all the requirements of the project before making any decision and assess whether you will be able to complete all the required tasks in your desired software.

- The downside is that we will not be able to 'hold your hand' outside of REVIT software in regards to tutorials and assistance, so be sure you have the required expertise within the company to do all the work!

Submission criteria for 2.4

1. Preparation of a design appraisal with appropriate drawing indicating at least two distinct and viable solutions for the proposed structure for the preferred Architectural scheme. The design appraisal should indicate clearly the functional framing, load transfer and stability aspects of each proposal.
2. Preparation of sufficient preliminary superstructure calculations to provide an approximation of the member sizes only, including the foundations.
3. Assessment of the type of foundations to be used from the site investigation report including an approximation of the foundation loads and sizes.
4. Preparation of preliminary drawings using the Architects drawings on to which the structural frame layout is to be indicated, and sketches to show the preliminary foundation layout.
5. Identification and discussion of the solution you recommend to be taken forward and the reasons for your choice.
6. **A 3D Digital Model on BIM capable software** will then need to be producing of the solution decided upon.

   The model should be of sufficient detail to be analysed in stage 3, it does not however have to be a final polished version. The idea is for the BIM analysis to inform changes required which can be implemented into your final developed design at stage 4. Tutorials will be provided to assist you in this process.

3. Stage 3- BIM Analysis and Interrogation

Weeks 11 – 15 (5 weeks). (Group mark 25%)

The analysis and data gathered from this stage should be used to **inform the developed design stage tasks**. There are multiple tools and processes within BIM that enable the user to **inform the decision making processes behind a project.**

There is a high emphasis on group work and design integration at this stage. All of the components from this task should be submitted as a cohesive package.

3.1. BIM Coordination

i. Continue to develop and compile the PEP document
ii. Continue to maintain the BIM coordination of the project

3.2. Amend of Design and Model Merge

(Assistance in merging process- Danny)

The model merging task of this stage will concentrate on data transfer.

- Ensure that the models are ready for merging and/or export and any changes advised from stage 2 are implemented, these changes are informed via feedback from the design tasks as well as the sustainability and build tasks.
- You will now be tasked to take the 3D architectural model and merge (data transfer) it with the 3D structural design model produced by the Structural Design Team;

- To complete this stage you will have to become aware and skilled in the practice of BIM data transfer and IFC data standards. (Additional information will be provided within the tutorial sessions to assist you in this task)
- After the merging process has taken place the company will need to review the model and assess whether any changes need to be rectified;

3.3. Investigation of Technical BIM Objectives

Within this section the company needs to investigate the technical BIM objectives as outlined in the following indicative list. The emphasis is on the company evaluating the processes and procedures involved in a BIM project. There may be successes or failures during this investigation but as a company you need to explore and reflect on the processes involved in a BIM project. The tasks that you carry will assist you to make informed decisions about your project.

Technical Indicative list (Documents and files to be submitted as an appendix within reflection report)

More examples of indicative content will be given at commencement of the stage below is an indicative list;

- Produce IFC files (used to share and import models into various software)
- Model Checking and BIM Model Validation using Solibri or similar software
- Clash detection (Solibri, TEKLA or software tool of choice)
- Data take-offs of materials, door schedules, window schedules will need to be produced;
- Integrate data take-offs from previous tasks into Spread sheets using Solibri or software of your choice (tutorials will be provided on Solibri)
- Data take-offs of Steel or concrete frame;
- 3D Scanning of existing building and features (Autodesk Catch 123 freeware tool);
- Carry out cooling and heating load analysis report for existing and refurbishment solutions;

3.4. Reflective Report from the Peer Assessments

Within this section each company member needs to look back at the results from the formative peer assessment which took place at the end of stage 2. Each company member needs to reflect on the results in terms of how they have (or have not) amended their behaviour over the course of the project. Due focus should be addressed to reflect on all of the feedback received from the peer assessment results.

Submission criteria for Stage 3

i. Reflection as a company on the BIM coordination process, amending the design and model merge and the investigation of technical objectives identifying how these tasks have enabled the team to use BIM to inform key project decisions.
ii. Each company member should complete a short report reflecting on the feedback received from the peer assessments
iii. Appendix containing the technical documents and files investigated.

4. Stage 4 - Developed Design

Weeks 16 – 20 (5 weeks). (Individual mark 50%)

Overriding Advice and Prerequisites;

Remember to use the PEP document to record your decisions and agreements on Company protocols. Take care to continually amend the PEP document as and when needed with updates on design and working protocol decisions. The PEP document will be submitted for review at the end of each Stage.

4.1. BIM Coordinator Task

The Project BIM Coordinator will be the overall BIM coordinator for the project. At each stage the BIM coordinator should ensure that all of the documents are up to date and correct.

Responsibilities will include;

- Develop, implement and maintain the BIM Project Execution Plan (PEP)
- Preparing the document for submission
- Ensuring that all 3D models are on track ready for the submission deadlines.
- Interdisciplinary BIM co-ordination
- Coordination task content Creation
- Record and monitor shared data and relationships between models e.g. grids, floor levels, shared project coordinates.
- Identify and agree any co-located or shared technical infrastructure needs, software package interoperability requirements and standards to be used by each company member to deliver BIM project.
- Ensure that the company continually link back to the progression of the decision making process throughout the project demonstrating how the team meetings and BIM analysis contributed the projects development.
- All key decisions and project developments should be recorded in the minutes of the PEP.

Submission Criteria for 4.1

i. Continue to develop and compile the PEP document, submit hard copy of PEP.
ii. Continue to maintain the BIM coordination of the project.
iii. Reflect on the experiences of being the BIM coordinator.

4.2. Sustainability Strategy

4.2.1. Company Specific Sustainable Strategy

(Module team member with responsibility – Abdullahi)

Now that you have completed your site survey and desktop study researching possible techniques, strategies and material uses to enable the design to achieve the high BREEAM rating that is required as per the clients requirements as well as the BIM analysis from stage 3 you should be integrating your findings into the architectural design and structural design package informing the design of the overall project. The research, analysis and design should be cohesive in nature.

Submission criteria for 4.2.1

i. A second report should be created outlining exactly what strategies as a company you will be integrating into your company's actual design in response to the previous desktop study and BIM analysis. You will need to include the desktop study from 2.2.1 as an appendix.
ii. All supporting documents created at stage 2 and 3 should be placed in appendix and referenced appropriately throughout your report. You should continually link back to the progression of the decision making process throughout your report demonstrating how the team meetings and BIM analysis contributed the projects development.

4.2.2. Survey, Specification and Costs

(Module team members with responsibility –Steve & Martin)

Now that you have completed your desktop study, site investigation and preliminary costing you should now reflect on how your findings from the previous stage influenced the overall project. The research carried out in stage 2 should be cohesive in nature with the overall design.

Submission criteria for 4.2.2

1. Your final report should be compiled, which should include;
    - Reflection on how your finding influenced the overall project
    - Detailed explanation and analysis of what changes were advised to the architectural, structural and sustainable design teams and what affect this had on the project from both the stage 2 tasks as well as the BIM analysis that took place at stage 3;
    - All supporting documents created at stage 2 and 3 should be placed in appendix and referenced appropriately throughout your report.
    - You should continually link back to the progression of the decision making process throughout your report demonstrating how the team meetings and BIM analysis contributed the projects development.
2. Detailed costing for the project to include detailed specification for the project.
    - You should use traditional methods of costing as well as including any relevant data take-offs from stage 3 BIM analysis.
    - All supporting documents created at stage 2 and 3 should be placed in appendix and referenced appropriately throughout your report.
    - You should continually link back to the progression of the decision making process throughout your report demonstrating how the team meetings and BIM analysis contributed the projects development.

4.3. Architectural Design

Same team as Task 2.1 'Architectural design team'

(Module team member with responsibility – Main Design Process– Heather, Technical Output - Danny)

1. Undertake the following architectural aspects:
    i. A set of dimensioned and annotated Architectural drawings in detail. (see next page for full details)

ii. The 3D digital model should be updated and amended as per the analysis and review from stage 3. Tutorials will be provided to show you how this can be done simply.

iii. It's important to note that the architectural design team will have to continually collaborate and communicate with the sustainability and structural design team to ensure that the project is integrated at all stages.

Submission criteria for 4.3

Site layout (1:200)

Detailed layout plans of all floors (1:50)

4 No. elevations (1:50)

2 No. cross-sections (1:50)

3D Digital Model on BIM capable software

4.4. Structural Design

Same team as Task 2.2 'Structural Design Team'

(Module team member with responsibility – Alfred)

Submission criteria for 4.4

2. Final structural design

iv. Structural general arrangement drawings

- Typical floor plans and elevations to an appropriate scale, showing grid dimensions, column and floor support beam locations and member sizes, floor spans, stability brace bay positions, foundation sizes etc.
- A typical section through the building showing general floor levels, floor thicknesses and construction, external ground levels, etc

v. Structural detail drawings

- A ground floor construction and foundation detail.
- A detail showing column-foundation interface.
- A section through an upper floor element showing floor construction and support method.
- A typical column/beam interface detail.
- Cladding fixings and its interface with the structure

vi. Preparation of sufficient detailed structural calculations to establish the form and size of all principal structural elements including the foundations, critical connections and the global stability of the structure.

vii. Preparation of annotated sketches outlining the detailed method statement of how the works will be constructed in a safe and efficient manner.

viii. The 3D digital model should be updated and amended as per the analysis and review from stage 3. Tutorials will be provided to show you how this can be done simply.

5. Stage 5- Presentations

Weeks 21 – 23 (4 weeks). (Group mark 15%)

Companies should present their final design package in a professional and well prepared manner. It is down to the companies to ‘sell’ their projects to the client representatives. As a company you should allocate the responsibilities of this stage amongst you as per your own deliberation. The best companies will work together to ensure that the best possible presentation package can be delivered to the client in an attractive and visually appealing format.

5.1. Hard Copy Printed Display

A selection of printed display material to present and ‘sell’ your project to the client. This material will be used in your final end of year public presentation. (The space available will be outlined to you at the commencement of this stage and you should make the most of the space you have been allocated!)

Submission criteria for 5.1

Any new printed material such as posters or banners should be submitted.

5.2. Digital Walkthrough/Flyover

A visual/digital walkthrough or flyover presentation of your design using any software you choose. You have the freedom to push yourself as far as you wish in this aspect. This material will be used in your final end of year public presentation. (Any walkthrough should be accompanied by the architectural team’s presentation/explanation of what the viewer is watching; this will be done in person as the project is presented)

Submission criteria for 5.2

Submission for task 5.2 is dependent on the method of presentation that the company choose to use.

Assessment Criteria

The module is structured such that you are expected to produce the work associated with the individual tasks. Each task will consist of its own aspects depending on the requirements of that topic. The brief has been designed to be open to allow you to identify what you feel is required as part of the project, rather than simply being given a list of necessary work to be produced.

As such a marking scheme is not provided for the following reasons;

Provision of a mark scheme will often cause projects to be directed towards the required tasks/criteria and will therefore potentially limit the possible content of each topic.

More importantly the module is designed to encourage you to think about the work that is to be produced and allow you to provide a solution to each task based on what you feel is appropriate.

However to provide some support, the following guidance has been produced to provide some indication of what the assessors will be looking for as part of each submission.

Level of detail – The assessor will review the work and pay close attention to the amount of detail that has been put in to the work. The level of detail will of course depend on the task being undertaken. Obviously some tasks that require precision, reasoning, judgement etc will require a greater level of detail than a task that may take a more general approach. It is up to you to decide on how far to go with this and this in itself is not easy. You should however, consider what the task is asking for and ask yourself whether a third party could understand what you have produced based on the level of detail you have provided.

Quality – All work that is produced should simulate documentation that has been put together by a company. Therefore the work should also simulate that level of quality. You as a company will need to impress the client; as such the assessor will want to see that you have thought about the presentation, layout and content of the report such that it forms a clear and comprehensive document.

Content – The submission should be focused on the task, therefore the content needs to be relevant. It is not worth including information for the sake of it as this will demonstrate that you do not fully understand the requirements of the task.

Quantity – Often it is seen that submitting a massive amount of work will result in a higher mark, this is not the case. The assessor of the task will be looking to see if you have satisfied the brief. Exceeding the brief is counterproductive; although this may be seen as an advantage, the client will only require a stipulated amount of work to be completed, so you do not always need to go beyond those requirements, unless asked to do so. However not satisfying the brief is equally problematic. Submitting 2 or 3 pages of work when asked to provide a detailed report will obviously result in a lower mark.

Clarity – Reports need to be clear and methodical. The information needs to convey detail and reasoning. The assessor needs to be able to read the submission and understand what it is you are proposing. It is easy to submit work that is understandable to the person who has written it, but a third part needs to be able to pick up the document, read it and also gauge what you are trying to achieve.

Accuracy – Being accurate in your work is important, but you need to ensure that you use the right level of accuracy for the task in hand. There is no point in specifying some information down to an exact point, if only a preliminary estimate is required. Consideration to the degree of accuracy demonstrates a greater awareness to the task being completed.

Resources – Using standards, guidance and other supporting documentation help to bolster and justify your work. The assessor will want to see that you have completed wider reading as well as seeing how this has influenced your work.

Engineering Judgement – Have decisions been made that are realistic? Or are your proposals unachievable? Ensuring that you demonstrate logical thinking is an important aspect of the project. Providing solutions that do not work or suffer from limitations and problems will limit the suitability of your project.

Appendix 14

Case study 1, 'Crash Investigation' 1st year Aerospace Engineering

Phenomenology of Learner Experience, Observations and Descriptions

1st Observation of Group 1 on 15/10/2013;

This observation was made during the learner's first tutorial activity. They were observed working through the flight log searching on acronyms, vocabulary and failure mode codes. The learners used desktop PCs to search through information about the case on the intranet, looking for repetitions and frequency of events as indications of likely cause/s.

2nd Observation of Group 1 and student reflective precis comments on 21/10/2013;

The presentation (given by 3 of the group) included an account of the crash time and circumstances, a weather report, eyewitness accounts of the aircraft losing height and structural damage. They also stated that flight recorder data was awaited. Speech was not quite clear but the main points were confidently articulated. They appeared to be reading from a cue. The 3 group members were each given a reflective precis proforma that asked them to specifically consider the decisions they had made. They all indicated decisions were made on when to meet to develop the presentation, its content and who would present. They all considered that team members had made equally valid contributions to the decision making. In response to questions on disagreement and alternative actions the following experiences emerged:-

> " I disagreed on how it should be written as we weren't sure of the style needed."
> " I disagreed with having one person writing and the others telling them what to write. It was all a bit disorganised".

> "Alternatives weren't presented because we were unsure of the audience which limited the amount of technical information we could put in".
> "We could have split into smaller groups and write parts. The group decision was that it would be easier to write as one group".

3rd Observation of Group 1 on 05/11/2013;

The learners need to identify the absence of any other necessary information and request it additionally. They have noticed a maintenance log report of a fuel leak that was corrected before takeoff and from the aircraft flight recorder, the pilot's voice recording saying "Where'd that come from"? At the same time there is a rapid loss of some considerable mass. Their current proposition is that the leak reopened when the pilot made an evasive manoeuvre. They are also of the opinion that the sudden manoeuvre was seen by eye-witnesses.

4th Observation of Group 1 on 07/11/2013

Week 6 and the group hold an extra tutorial meeting at Priory Hall. Four team members were present, two actively engaged in the debate and using laptops, the other two much more passive and observing. The description below summarises the main features of a discussion lasting over an hour. I have divided the discussion into five segments to enable an analysis to be interleaved at convenient points roughly delineating the changing focus of the discussion. The principle disjuncture in this observation occurs because the learners cannot easily explain the sudden loss of mass from the aircraft. The problem space is populated with a series of propositions that they have to make judgements on in order to close the disjuncture. These are conflicts about the potential effect of a violent manoeuvre, a fuel leak, the cargo load, engine failure and eyewitness reports.

<u>Segment 1</u>

> “The rate of turn indicates an evasive action took place.”
> “There are massive changes in X! I don't think this is a fuel loss!”
> “The incident angle goes from 97.5 to 4.6 in about a second, so a fuel leak is looking very plausible.”
> “The leak doesn't occur until in flight and this is more than a little leak yeah? Sounds more like the wing has fallen off!”

<u>Segment 2</u>

“Airspeed? it's more likely to speed up or slow down if he sees something. How? when he's panicking? Hands on throttle?”
“The pilot says it's time to relax! yeah 'cause now they're climbing.”
“What's the true airspeed? It's pretty obvious it's going to increase.”
“The rate of climb is not very promising.”
“Trying to pitch up to regain control, trying to use flaps but they rip off - laughs.” (humour)
“Looks like a definite fuel leak, we could have a look back at the reports.”
“Didn't it say there were 2 bangs?”
(more humour, discussion drifting - ego depletion)
“Was there anything reported in the pre-flights? Fuel leak? No, the last one was light.”

<u>Segment 3</u>

They begin to consider the airplane load and whether the shift *in mass can be attributed to that.*

“What about load factor, passenger weight shifting?”
“It doesn't affect it that much.”
“There was a crash caused by passenger load.”
“I don't think load is a problem since they actually took off.”
“The cargo is a red-herring. Do we have the cargo weight? If it is safe then OK.”
“It might shift with an evasive action.”
“Some of the Q1 is incorrect I know that for a fact.”

Off topic discussion of TV programmes 35 minutes into meeting.

<u>Segment 4</u>

“The right engine stopped that's why it feels strange, that's why the plane moved not because of evasive action."
“The unexpected reference point is "Where did that come from"?
“What effect does fog have?”
“Negligible except for visibility the strobe light is for visibility only, you don't fly visual in class A airspace you have to use instruments.”
“That could have been the cause of it!
The learners engage in an off topic discussion.

<u>Segment 5</u>

"Why is there such a massive fuel loss? Either the sensor is faulty or both wings fell off. We need to figure out why the fuel leak was so big."
"Are there any post crash reports? Was there a fire? No fire indicates no fuel. One tank still has fuel."

"What is the minimum number of engines on which they can fly?"
"Did the ground crew inspect the wing."
"Is there anything else we can think of at this point?"
"No"
Brief discussion on references.

5th and Final of Group 1 on 26/11/2013;

Five members present, four actively engaged in activity with PC's and one passively engaged. This is the last group meeting prior to the presentation of their findings and conclusion.

"The engine is loose and there is a continuing fuel leak, avoiding the harrier jump jet stressed the engine mounts and the engine broke free."
"If we had a debris field report we could have proven this from the debris field."
"Is there any evidence the engine was loosely fitted?"
"J Thinks it might have, the evidence would be in the maintenance report."
"Are we OK with the presentation video?"
"Yeah?"

2nd Observation of Group 2 on 22/10/2013;

This group have prepared a professional looking backdrop for a news desk. The newsflash is succinct and relays all the currently known facts about the crash. There is a speculation that a fault is the cause. The eyewitness reports are almost inaudible but refer to flames and smoke. The video finishes with credits and a soundtrack from BBC News. Four members of the group gave a reflective precis of their experience of making the video.

"We had to decide where the video would be filmed and who would do what part/role depending upon our different talents."
"We decided to make a video that was informative but not provide all of the information that we had discovered."
"We had multiple takes of each scene of which we selected the two best and then someone had to choose one."
"This meant we had multiple copies of the video as a backup for an unforeseeable event."
"The script writer could have played the eyewitness but as they didn't want to appear on camera we had no choice."

1st Observation of Group 3 on 15/10/13;

Two members of the group are working directly on one PC the remaining four are observing and following the discussion. Activity is primarily an examination of the flight log to clarify information and structure, comparing the printed flight log with on screen detail of the aircraft. In this they are exercising the discriminatory judgments of identity, similarity, membership and difference. They have decided their initial explorative examination should focus on engineered components like fuel tanks, engines, landing gear and possibly judgments of analogy with other aircraft systems failure as opposed to incidental causes or human error. In overview this indicates judgments of composition and relevance about the initial problem space have been made.

2nd Observation of Group 3 on 22/10/13;

Five team members present their newsflash. Each team member gave a reflective precis of their remembered experience of the development. The newsflash gave essential information about the aircraft, the crash event and weather conditions. Two eyewitness reports are included in detail, one from the perspective of a retired aerospace engineer who saw the aircraft out of control with structural damage followed by an explosion and one from a car driver who saw the crash and the aircraft in several pieces. They go on to introduce information about the ATC report on a flock of geese and the replacement of an autopilot.

1st Observation of Group 4 on 22/10/13;

First recorded observation of this group was made during their presentation of the newsflash. Using aircraft parts for props the basic facts of the aircraft and the incident are given and the need to locate the flight recorder (some shaking of the camera). One of the speakers is almost too quiet to hear, however there is some speculation about possible causes such as human error or mechanical failure. Eyewitness statements are emotive and express feelings as well as observations of smoke and falling aircraft. They inserted a gag reel at the end of the newsflash with a number of out-takes.

3rd Observation of Group 4 on 19/11/13;

Four of six team members are present and planning the presentation using moodle for dates. 2 PCs are in use and there is little discussion. The sole female member is working alone on a data sheet to generate graphs of the flight recorder data.

> "I think we have nearly everything, just need to double check."
> "Report assumptions. what we think happened with conclusions and evidence."
> "Your hypothesis?" *Prompt from me*
> "Technical problems, fog, another aircraft within 100 metres maybe a collision.
> "Have you changed your viewpoint?" *Prompt from me*
> "No not really,..... one of the flaps/aerofoils got stuck

4th Observation of Group 4 on 26/11/13;

3 members of the team are present and discussing the delegation of workload for the actual presentation.

> "We'll do the allocation first then discuss this later on."
> "Research, data sources, method how did you get to the conclusion."
> "The tutor explained the purpose of the project and the assessment."
> "Wants it done latest Tuesday."
> "Your hypothesis?" *Prompt from me*
>
> "A Harrier suddenly appeared, there was an evasive action, something jammed and the pilot couldn't recover."
> "We need to refresh our memories of all the data."

There then followed a brief discussion between team members on distance, visibility and a study of the air proximity report.

Group 4 Final Presentation Video

The group present their findings to the tutorial panel. The first six and half minutes is taken up with presenting the background scenario and the findings including a detailed explanation and surmise of graphs from the flight recorder data. They presented a number of causal judgements that had been considered and dismissed and their ultimate conclusion is that the A320 stalled after the evasive manoeuvre and a wing tore off during the time the aircraft fell to the ground. It is very difficult to see how this wing loss scenario was developed from previous thinking. It may be possible that they became aware of a wing loss scenario by implicit means and attempted to fit that explanation in to their existing problem space. The difficulty in doing this and without understanding is that the narrative is no longer coherent. In the way they reported the final conclusion the wing would have torn off some time after the loss of mass recorded by the data recorder. That is not only not possible it would not lead to an attribution of causality because the sequence of events is counter intuitive.

1st Observation of Group 5 on 05/11/13;

This is week six and five of the six team members are present, they are using PCs with dedicated software and now have access to all the information and data sheets provided by their tutors as part of the project. The present investigation involves the use of MATLAB to analyse the Flight Recorder data.

> "The flight take off was normal."
> " Pilot response?"
> "Autopilot, collision light, the autopilot was on, aircraft uncontrollable, upgrade to CAT2."
> "Possible leak on wing, possibly fuel."
> "Not ruled anything out, geese, flaps stuck, hydraulic problem."
> "The weight isn't right. possibly aileron, slide slip."
> "Bird stuck in aileron then?"
> "The seal (fuel) wasn't changed, Airbus said this needed doing within a certain timeframe."

2nd Observation of Group 5 on 25/11/13;

Week nine, Four of the team are present. The main activity is a discussion with notes and hard copies of data.

> "The fuel leak wasn't repaired, there was a sudden fuel loss that was ignited by another plane's engines."

Judgements of hypotheticality and causality

> "Three tons of fuel in one second, doesn't explain the loss of the starboard engine 5 seconds earlier!"

Judgements of factuality sufficiency or absence of information

> "There's no real data on the other aircraft. We need a report. It could be a combination of things."

Judgements of factuality sufficiency or absence of information, hypotheticality of significance of the other aircraft

> "The seals weren't changed according to the Air Worthiness Directive."

A judgement of practicality

> "We could use the Flight Simulator to replicate the scenario to see what really happened, just to see if it is possible to keep control of the aircraft."

Judgements of hypotheticality, analogy and reference

> "Angle of attack data from 20° to -2° ~ -3°, it looks like it stalled."

Judgements of measurement, analogy and causality

> "Then it goes positive again." They changed the autopilot so it could be something to do with that."
> "We know engine malfunction isn't the main cause but we need proof."

Judgements of factuality, hypotheticality,

> "We should start writing the presentation."
>
> "But not until we have all the information and a common point of view."

Judgements of practicality, instrumentality

3rd Observation of Group 5 on 26/11/13;

4 members of the team are present researching and finishing the write up for their presentation. When prompted the joint response was;

> "The flight simulator showed that the pilot could cope with one or two engine failures so we ruled that out, but we still think it was an oil leak that caused the problem."

There was no further justification offered at that point.

4th and Final Observation of Group 5 on 05/12/13;

Five members of the team present their findings and conclusions supported with display screen graphics. Beginning with the background to the accident they provide a spoken report of what they perceive to have been the facts. The air proximity report refers to a near miss within 100 metres, the pilot's voice from the CVR and the sudden changes in the aircrafts attitude, an evasive manoeuvre. They then speculated that the starboard engine failed as a result of the evasion and contributed to the crash. However, the flight simulation showed engine failure alone was not a factor and they had ruled this out. They proceed to put the argument that an engine flame out and a pressure 'surge' from the other plane caused a hydraulic failure that affected the flaps and controls so that the aircraft spiralled out of control.

1st Observation of Group 6 on 15/10/13;

Four members of the team are present, the main activity is analysing the flight log and maintenance reports. The group activity is not particularly focussed, they appear to have fallen into certain tasks rather than tried to do them in an organised way. They are seated in different parts of the room, making team communication difficult.

> "This is the fifth piece of info, nothing seems to stand out but he's just spent some time going through it so it must be important."
> "What are aircraft maintenance checks A, B and C?" (confirming concept using search engine on PC)
> "It's like an MOT for an Airplane!"
> "Find out when we do the news flash. Got camera and tripod, need to organise the group."
> "Some checks are satisfactory, they won't reveal anything so I'm putting them out of my mind."

2nd Observation of Group 6 on 12/11/13;

Five of the team members were present. They used PCs and MATLAB to produce graphical plots of the flight from flight recorder data. In the following dialogue they are interpreting the graphs and develop a narrative around fuel loss that explains what they intend of the data. After my prompt there made a few mediating judgements where the idea of fuel loss is still the focus of their thinking. The difficulty they have is explaining how the fuel loss could be so large and abrupt. The idea of something more catastrophic is posited. My analysis of the judgements is interleaved after each comment.

> "Just done a graph of fuel against time and there was a massive fuel loss, like it's just all gone. "Not sure what it means yet."

A judgement of measurement

> "It goes down and back up, it could just be the way the plane measures fuel." What if the drop was so severe that the fuel 'went up' so that it didn't register?"

Judgements of hypotheticality and causality

> "I don't know how a fuel tank would work."

Judgement of appropriateness about self capability

"If the attitude is still level during the fuel loss then there is a big descent."

Judgements of hypotheticality and causality

"Do you have an initial hypothesis?" - prompt from me.

One of the students gives a bewildered look.

"We've looked at the Air Worthiness Directive about the fuel seal requirement and we are considering fuel loss."

Judgements of practicality and relevance

"The centre of gravity changed rapidly at one stage."

Judgements of measurement and factuality

"Yeah, that's when the fuel goes."

A judgement of causality

"Yeah but these are all effects that we need to find the cause for."

Judgements of absence or coherence

"Looking at an image of an A320 and the fuel tank location. It lost 99% of its fuel in a second?" "It can't be a leak, it must be an impact or something, an impact on the starboard side."

Judgements of measurement, relevance, hypotheticality and causality

3rd and Final Observation of Group 6 on 05/12/13;

Four of the team make their presentation. The presentation was structured and comprehensive beginning with the incident details and details of the flight and ground crews experience and qualifications. They summarily dismiss the eyewitness accounts except two, one from a retired engineer and another from a flight engineer. They note the aircraft was loaded correctly and refer to the Flight Recorder analysis where they used excel to generate graphical outputs. The attitude of the aircraft is mentioned together with loss of starboard engine power and fuel loss. Their culminating causal judgment of the crash is that it was as a result of the loss of the starboard wing caused by an explosion of leaking fuel.

Appendix 15

Case study 1, Phenomenology of Learner Experience, Semi-Structured Interviews. From section 5.3

First Semi-structured Interview.

Their solution to the project scenario is only partly correct.

> "It came together toward the end, we presented better than I thought we would.
> "It was very difficult to get people to show up to meetings, lot's of obscure excuses. It was hard to make group decisions."

"So how did you get to choose who did which part?"

> "I allocated different data analysis tasks, that's why whoever did the analysis also did that part of the presentation."
> " It ended up with me having to make decisions based on who showed up."

"Was their input missed?"

> "It's hard to say, they may have come up with something ingenious but their input was minimal."

"What was the cause of the crash?"

> "The pilot tried to make an evasive manoeuvre that opened up the fuel leak causing the starboard engine to stall."
> " It explains the massive fuel loss."

"Where there any especially salient or significant decisions."

> "One of the big ones was making the decision to do 7 of the 10 slides because I wasn't getting much response. I gave them 2 - 3 days and at that point I had to do it."

"How do you feel about that?"

> "Annoyed about the deadweight in the groups, most of the input came from me and 2 others."

"What about the technical demands of the project?"

> "It was difficult at first, a new experience dealing with that kind of data. By the time we came to do the presentation I felt I understood it reasonably well."
> "Our hypothesis was developed seventy five percent from graphs of the flight recorder data on the starboard engine thrust. There was also the fuel leak. This was built into the scenario with the manoeuvre to avoid the harrier."

"Are you satisfied with this solution?"

> "Yeah, we might have come up with something different if we'd had input from everyone, but it made sense to us so we went ahead with that."

"What would you do differently?"

> "Definitely I think starting to work earlier on the presentation. More likely to get a few meetings together and be more clear on what needed doing and when. Organising the team was the most difficult."

Second Semi-structured Interview

Group participation had been poor and there was some difficulty at the presentation, the sudden appearance after 5 minutes of a team member who had not contributed to the solution resulted in some tension. Their solution to the project scenario and argument is largely correct.

"What can you tell me about your project?"

> "I'm not angry anymore - it upset me."
> "We all tried to get there with a conclusion, took roles according to strengths."
> "The others had been asked to chip in but two didn't input to the presentation and one didn't help us at all."
> "Organisation was reliant upon two proactive members and it was hard to fill the gaps."

"Do you think this experience was extreme?"

> "In the sense that people pay, but I'm not the only one. It was unnecessary stress, I felt the group volition depended on me."
>
> "There were no clashes but personalities weren't supportive, there was no particular drive. We were put in a group by the tutor so there was no choice of who to work with."

"What were the significant decisions or ideas?"

> "One did a lot of work with graphs that supported the hypothesis that a wing fell off. I was adamant that a wing had broken off because there was a shift in the centre of gravity and 4 tons of mass were lost. Others disagreed, I'm not going to remember exactly but fuel was one idea. Another thought there was a pitch malfunction."

"What would you do differently?"

> "I'd choose the group (laughs) I don't feel the need to pester people to do work though I did text people."
> " One wasn't even prepared for the presentation but volunteered to do the introduction, I said any of us could do that".
> "If we'd let it, it could have ruined the presentation, it almost did but three of us presented it."
> "I went into the presentation thinking it was a dead end."
> "I asked one, 'Do you honestly think you should get the same marks as us?' There was no reply."

Third Semi-structured Interview

This group worked in close proximity to each other but tended to work in pairs rather than as a whole group. There were few protracted exchanges of views or dialogues between the whole team. The female interviewee is not a native speaker of English, but sounds confident and articulate. There were no instances of difficulty with vocabulary during the interview.

" How do you think the project went?"

> "I think it went well. we were not too pressured for time and managed to distribute the work."
> "There were a few times in the last two to three weeks, only two turned up to meetings. Some are more or less proactive, I guess it always happens. They literally can't be bothered."

" What was your conclusion on the cause of the crash?"

> " Avoiding the Harrier, the airplane crashed into the flock of birds damaging the fuel system."

"How was this idea developed?"

> "In the beginning we all bounced ideas, toward the end the two guys left it to us."

"Why do you think they did that?"

> "Not sure, I think they didn't have a better argument to convince us so they just stopped."

"Was there a significant decision?"

> "Not really, the birds was the one thing that made sense together with some other things."

"The most difficult aspect was having to read all the technical reports without knowing what some of the things meant."
"We had to ask the tutor or look it up on the internet."
"It was hard to find information on air crashes."

"Did you find the learning experience difficult?"

"I don't know, I have learned some things but maybe if they showed us how to do it, it would have been better than just feedback."

"Would you do anything differently?"

"No, they haven't really told us how to do it so we'd probably do the same thing again, maybe read some more on air crashes."
I'm not sure about loss if input, because like when they were more involved they weren't the ones giving the main ideas."

Appendix 16

Case Study 2: Design and Construction of CNC Work-holding System.

Phenomenology of the Learners' Experience.

Logbook entries for Group 1:

4th October 2013

> "This week A and myself are researching and estimating our project costs. S will research what the current operator and machining practices are on the shop floor and note any key issue. All of our planning was accurate, we all had an input. We worked well as a team, good communication."

18th October 2013

> "This week we have decided to look further into what forces will be applied to the fixture. We'll look at the clamping points and which location points can be changed or relocated to permit machining. Actions:- to research lever mechanisms, update risk register and costings. Our planning was accurate, maybe we'll meet up half way through the week to discuss progress. There were no alternatives considered"

25th October 2013

> "The work planned for this week is to discuss current machining practice set up with operators, finish the project plan and look at materials and prepare final costing. The final costing is very similar to our initial estimates, a few items have been amended and more cost implications added. Still a work in progress. Better alternatives could have been made."

1st observation of Group 1 on 1st November 2013

The team was observed in the very early stages of their project working on producing a Gantt chart, risk matrix and risk register and researching material properties and costs with an iphone and mobile internet connection. They discuss what the potential project risks and timeline could be. Their immediate objective appeared to be acquiring the information to produce an initial ball park cost for their solution. Ten operational threats to the project were in their risk register, including material availability, consultant availability, design errors, team absences, overspend, work capacity, specification change, machining problems, machine availability and poor information.

Logbook entries for Group 2, 1st November 2013

The earliest logbook entries made by this team were lists of notes or actions with little or no narrative and the log records omit important aspects of their thinking that was more readily accessible by observing them. For example their intention was to use a tombstone type fixture but it is not recorded anywhere in the log or their reasons for it. This may have been due to uncertainty regarding how the logbook is used and the level of detail rather than a conscious decision to omit it. From the logbook entry made on the 11th October, the team planned to determine the location points and show where they are situated on a sketch with the bonnet guide. There was also an action to revise costing.

On the 18th October they planned to discuss various methods of clamping including pneumatic, manual, rack and pinion and toggle mechanisms and bolt through methods to arrive at a concept from which they can work.

From the entry made on the 25th October, they planned to work on their project plan, revised costs and risk register. However they recorded their actual actions as:

> "We researched different applications for clamping methods. From the research we realised that some of the methods we considered were more difficult or expensive to do.
> "We decided to use manual toggle and rack and pinion."

In reflection and evaluation they wrote,

> "The plan was not fully completed, we felt it should be done when we were together as a team. We will complete the planning in our own time in the log book."

1st observation of Group 2, 1st November 2013.

There is very little discussion taking place, their original ball park figure of £9483.75 is now £28,806. The increase is due to revised time and labour costs after research on real employment costs rather than just hourly wages. Their initial project Gantt chart has headings only, time projections are absent and the risk register is quite high level with all risks accumulated under 'missed deadlines'. The work they have planned is to revise the project Gantt chart and risk register, research cam clamping and draw the concept sketches for the fixture. Their discussion reveals they have an idea to use a tombstone configuration in stainless steel for the fixture and cams to clamp the component. This will enable tandem machining but location still needs working out correctly. An alternative they considered was to use 'through component' screw clamping that would require some component rationalisation.

Logbook entries for Group 3: 4th October to 1st November 2013

Log entry for 4th October.

> "Given a project for the machining of a bonnet guide with current machine routing document and drawings. Discussed ball park costs in project, e.g. labour etc. For next week, consult production engineers and discuss machining practises and problems and research pallet work holding. We didn't finish work on ball park costs due to lack of understanding between each other on what costs needed to be covered. Production engineers are not on premises until next Monday."

Log entry for the 11th October.

> "Confer during week to complete ball park costs, set up meeting with the production engineering department (PED) to discuss current work holding problems. We completed the ball park costing and time estimates. A discussion with PED took place but could not arrange a meeting. We looked into toggle and cam clamping mechanisms. We were unable to arrange a team meeting and had to rely on text messaging for planning actions."

Log entry for the 25th October.

> "Research harder materials for fixture, mild steel isn't strong enough and cannot be through hardened. B will fill out project plan and decide order of tasks. L to revise costs and increase machining time, design costs, consultant costs to give new total. Everyone to set up a Gmail account and folder to store work." The reflective section was not completed.

1st observation of Group 3, 1st November 2013.

The initial ball park figure for group 3 is £8691 and based on local case studies history. Their current work focus is machining research, concept design and project management documentation. The Gantt chart shows no durations and they are considering the merits of using a table instead. The project plan shows they intend to provide mechanical analysis after completing CAD drawings. Their defence of this position is they are focussed on benefits to the company and also they will need to change the design. They are undecided as to whether they will use a cam or toggle clamp. They have now considered the use of a precipitation hardening Tenzalloy aluminium alloy for the fixture.

Logbook entries for Group 4 11th October to 1st November 2013

11th of October.

> "Produce a 'ball park' costing for a prototype estimated time one week. Research types and costs of hardened steel. AISI 316 casting to be used. Machining processes, previous experiences and previous problems to be investigated by S. 5.83 hrs machining time for fixture (6 x £15), fixture design £1554."

1st observation of Group 4, 1st November 2013.

Group 4 are not working well as a team, discussion is sparse and there is no generation of ideas. Their current work is revising ball park costs and the project Gantt was started today, together with some work on concept sketches and clamping methods. Screw clamping is being considered and they have to realise at some point that it can't meet the specification. Revisions to costs now include an amount for expert consultancy which they have researched. They intend to allow for one days consultant time. The risk register is missing but from their rough notes, identified risks are all related to machining stoppages or tool breakages, they have not identified any operational or strategic risks for the overall project. Initial project plan at the end of this session lacks detail, all stages are consecutive and there is no concurrent work planned. The design stage appears to be allocated to one individual.

2nd observation of Group 1,2,3 & 4, 8th November 2013.

Group 1 are discussing project Gantt chart and milestones, quality control and what should be 'in' or 'out'. Other discussion focuses on the component to be machined and whether there is any necessity for machining the posterior surface. The female team lead is influenced by previous experience and thinks they should check current practice. The possibility of machining two components in one fixture is also being discussed. One of the team says they need to review where they are and set action points for future work.

Group 2 are discussing potential variation in the size of the castings and the effects on choice of location. Straightness and parallelity are the current points under consideration. At one point, one team member is off task playing a sound track from his iphone. Others are completing their logbook and updating project documentation on a laptop. Four strategic deadlines and eight operational risks are now listed in the risk register. There is some difficulty in making judgements of membership and categorising strategic from operational issues.

Group 3 are still putting together a draft of their project Gantt, they are using a template from a training company. One team member is explaining the content to another. From the discussion it emerges they need to look to tasks that will run concurrently and allocate those tasks. Dates need to be decided, the current scheme doesn't show any draughting time and there are four deadlines. Other discussion is around whether or not to use a cam for clamping.

Group 4 production engineer group is absent. They are aware the project plan and Gantt chart need to be improved however, action is rather slow and a lot of time is spent 'gazing'. They revisit the ball park costings - it is very low and the way they have costed it out is unclear. They are depleted approximately 1.5 hours before the end of the session and stop work.

3rd observation of Group 1 and team lead interview, 15th November 2013.

It is week seven of the programme and the fourth week of the project, 12 hours of tutorial time have elapsed. Group 1 have increased their costing by £20K based on 'shop floor' research on total hours available against actual or potential cutting time. The mass of material is being calculated and they plan to acquire costs from the company purchasing department. Some very basic sketches have been completed, one shows a 'bolt-through' 2 stage fixture which will not meet the load unload time requirements and a second sketch that shows corner locating pins and cams. They are unsure of the type of cam they will use for clamping. They discuss the mass of the component and how much material has to be removed. They upload the Gantt chart to cloud storage after requesting an example of task dependencies.

From a brief interview, the intentionality of the team leader can be inferred. Her judgements of factuality and appropriateness are that the current problem space is incomplete or in part incorrect and an alternative method should be considered. She makes a judgement of practicality regarding the use of tenons.

> "What is the current status of your project?"
>
> "We'll have to revisit the location and clamping again."
>
> "What specifically do you think needs revision?"
>
> "I think we need to reconsider clamping and look at using over centre clamps and locating on pins. I think we need to locate the base plate on tenons."
>
> Me - "I'm looking at the work load, has it been decided who does what?"
>
> "To be fair not yet"
>
> Me - "Not yet?"
>
> "I have an issue with person X"
> "He's being really.., I dunno, awkward?" her mood changes, she sounds irritated and resigned.

3rd observation of Group 2, 15th November 2013.

Group 2 are in discussion about the pallet specification, load times and maximum permitted mass. Referring to the component drawing they discuss the issue of whether the posterior side of the guide needs machining. They are unsure if it is necessary and ask me. I tell them this is something they must either find out or decide themselves. They plan to use shop floor anecdote to make a decision. There is a standard routing report with this information that they have possibly forgotten. They discuss at length bolting the pallet to the base plate and have to be told this cannot meet the specification load/unload cycle times and it would remove the need for a pallet anyway. The team lead is doing some of the concept sketches and two others are watching this activity. In a one to one discussion with team lead I express concern about work load in the group, there is a fair amount of time spent off task and time isn't spent profitably.

> "X is putting the Gantt chart together and we have all had an input to that."

> "I'm doing the concept sketches, (pause) I'm a better drawer, we have discussed the concepts and issues."
>
> "What's Y doing?"
>
> "He's been helping X and me."

3rd observation of Group 3, 15th November 2013.

Group 3 have not maintained their project management documents, the project plan doesn't reflect their current position and needs revising. It also needs dates and it is unclear as to what is included in actions. There is a reference to CAD drawing that indicates they are weeks ahead of schedule when in fact they are behind schedule. The group are discussing the component and whether the profile and rear faces need machining. The discussion centres around rational deduction and alternatively whether they should consider shop floor anecdote. There is some confusion over the purposes of a pallet and base plate fixing system.

3rd observation of Group 4 and group lead interview, 15th November 2013.

Group 4 are working on project Gantt and task dependencies, a plan has evolved albeit slowly. They appear to be reworking costs or copying out from draft? one hour into session still in project planning discussion trying to think through required actions. Their revised ball park cost is now £48,417 after revision of the estimated projected time for machining. A discussion with group lead reveals they still have some difficulty in problem space definition and the group are now intend to rely on one individual with access to Solidworks to provide concept drawings.

> "We are revising the concept for the fixture to use pin locators instead of parallels. We thought we would use angled threaded pins for clamping."
>
> "The current sketch represents an idea but it needs re-doing, Y will do the revised sketches of the work piece clamping but X has access to solid works he's confident that we can clamp the pallet to the base plate with a mechanism under the base plate."
>
> "I'm researching materials and checking we can keep within the specification for mass, we may go for EN24."
>
> Me - "What about locators?"

"I'm not sure, it's something that we have to discuss."

Me - "You need to decide datum and location before you can determine clamping.

4th observation of Groups 1,2, 3 & 4, 22nd November 2013.

The lead for Group 1 is on holiday this week and two remaining group members discuss locating the pallet on the base plate with dowels and locking down with snail cams, using lighter materials so that 2 components can be set up on one pallet. The discussion turns to 2 clamping operations to complete machining but the only way to do it requires a change of datum. They're not sure if the sides of the component need machining but know that some of the castings have profile defects. They're also aware they need to qualify their decision and can't do that with shop floor anecdotes. They note the cam clamping mechanism mustn't foul the cutter approach or crush the work piece and the positioning of one locator could foul some drilling operations. The cam in their sketch is lobular. They agree to revisit the machining operations and survey the type of machine used in actual production. Loading the pallet outside the machine is discussed and the increased blow down time if 2 components were loaded at once. They conclude that a 2 component pallet would probably take too long to load and unload to meet the specification. 11:30 and work has stalled. Later they have an idea that springs or a spring detent would be needed in the clamping mechanism.

Group 2 confirm their design will incorporate a small tombstone like fixture with cam clamping mechanisms. The issues immediately under consideration are the total mass of the fixture and calculating the work piece clamping forces. They assume that they can extrapolate their reasoning on clamping to secure the tombstone to the base plate. Their current design calls for the fixture to be machined from solid but they are also thinking about fabricating it and machining the faces afterwards. They have estimated that 45.5 hours will be sufficient to complete the machining. Later, one learner is working on their design presentation for the first deadline and the others are doing concept drawings of the fixture, they are discussing dimensions of the base plate based on the footprint of the tombstone. They become aware that the tombstone will become bigger if they include ledges for clamping, ½” keyways were considered sufficient.

Group 3 has established their principal concept, the group leader is calculating the rise of the clamping cam and clamp forces. Others are doing concept sketches, general arrangements and part detail. The overall size of the cam mechanism has been increased, they explain it was to cope with the clamping forces. Intuitively they decide the cam must be a hard material, they have put the maximum rise on the cam at 1.25” and assume it will rotate 45°to engage. One learner is sketching the cam and follower, they have decided to machine a shallow flat on the cam face at the point of engagement to prevent the cam from slipping. Another is working on the base plate and asks whether 12mm through bolting would be OK. There are three locators for the pallet to the base plate and the idea of locking down with a toggle clamp is discussed. The group lead is doing some free body diagrams for the clamping watched by one other. The dimensioning appears driven by the current perception of the size of the cam. The travel on the follower is 1.7". One examining the drawing thinks the sizes are wrong and questions why the dowels are only 0.1" long. Another, claiming he intended to state this some time ago, says it shouldn't be too high, just enough to locate and swarf control will be easier if the location is lower. However there is now a concern about having sufficient clearance above the pallet to permit drilling operations. Note these apprentices often work in imperial units because they machine for the American market in their daily work.

Group 4 are considering buying in a cam clamp and fitting it to their pallet design. They are still looking into material properties and revising concept sketches to show the locating pins in the correct places. They plan to use two over centre clamps fitted inside the base plate to locate and lock the pallet to the base plate and to secure locating pins with grub screws instead of press fitting them. Sketches of the arrangement have been made ready to be dawn in solid works. A one to one discussion with group lead reveals there has been a development in this group, they previously made a decision that one person should do the concept work on a CAD system.

> "X has done something on Solidworks but it's different to what was agreed by the group. We'd agreed that locators would be slide fitted and grub screwed but he has altered the design so that they are press fitted. No idea why he's done it I think he's been listening to people from his department."
>
> Me - "Was his idea for the change communicated to the group before it was made?"
>
> "No he just went ahead and did it. There's no reason why he couldn't do as planned from the sketches and the end face locator he has re-

positioned will prevent machining of the bolt end face. We'd have to have two set ups."

"We thought that holding the locators with grub screws from the side would enable easier replacement for the client. The whole point is to make operation easy and quick and we needed to think what if?"

Me - "OK, I think you need to get back to the group discuss the pros and cons and come to a decision quickly."

The issue is still unresolved after two hours arguing. X won't budge. I suggest they write down their reasons in their logbook for future reference. Y has depleted at this stage and has disengaged. X is watching the group lead write up the logbook. The debate was centred on the additional work and difficulty of fitting grub screws and client convenience against the requirements for precision press fitting. Eventually the decision is put to a vote to overrule press fitting.

5th observation of Groups 1,2 3 & 4, 29th November 2013.

It is week nine of the programme, sixth week of the project and group 1 are sketching mechanisms and an issue of fouling cutter access to the bolt end face arises. They discuss locator positioning and the group lead reaches for a calculator. The discussion turns to locating, loading and how to incorporate poka-yoke. One opines,

"I think an operator could locate this incorrectly."

"If they can't see a 180° mislocate is incorrect they shouldn't be employed."

"We have to demonstrate that we have taken this possibility into account."

"The base plate isn't lifted during the load reload cycle so it's mass isn't an issue during operation."

"I thought we were going to make the locators bigger?" I'd say 15mm, 10mm doesn't look very........"

"At that thickness we'd have through holes and dowels and we don't want that, dowels aren't fitted in through holes."

"Let's thread the dowel pins then."

"Then they won't be dowels."

"Do we need an interference fit?"

The Group lead explains a sleeved dowel arrangement. They discuss the idea of slotting the edge of the pallet in order to take a snail cam. The group lead puts forward the idea of using Lenzkes clamps but the group don't think that will be fast enough. There is a an exchange on using cams in clamping. The group leader discusses with the group the distribution of work and the need to clarify concepts through the sketches paying attention to location points and strength of parts.

Group 2 are discussing the mechanics of clamping with their current concept sketches. Final location points still need to be determined, at present only 2 locators are shown. They are scaling the sketches with a rule rather than producing free hand drawings. I ask them if they are revising the whole concept again, they respond that they are making some adjustments otherwise the cam won't fit. One is now working on their presentation, another refers to Zeus tables. I ask them what they have left to do and they confirm that there are just materials to confirm and complete the free body diagrams and calculations. One asks, "Do we need to calculate speeds and feeds?" Another responds saying, "Sure, they determine the cutting forces that the clamp has to sustain." The group lead allocates tasks of calculating speeds and feeds, finishing the sketches with locators in position and confirms the presentation should have costings and project management.

Group 3 are revisiting project planning, the project Gantt chart is displayed on a laptop, there are some drawings of different cam mechanisms and the group logbook. The locators look correctly positioned and they are attempting to work through the free body diagrams and mathematics. They begin to discuss the order of machining, a learner from group 2 interjects and there is some cross group talking. Their knowledge on machining has been taken from operators on the shop floor. One asks the group lead, "Have you spoken to the designer?" "No, I have to don't I? (looking at me) it's logical though isn't it?" 10:25, one is appending dimensions to a sketch, the group lead is still working on mechanics calculations. Another is doing an internet search for toggle clamps. They discuss the size and position of the locating pins, welding or bolting the pallet together or the possibility of machining it from solid.

Group 4 is browsing solid works drawings on a laptop, no discussion takes place no action. The group lead is absent and hasn't contacted anyone to say he was going to be away. 08:20 One is attending to log book entry and the other is off task with an iphone. 45 minutes in, they discuss the disagreement they had last week.

> "Instead of grub screws we could counter bore and bolt from underneath?"
>
> "I think it would be less trouble to maintain."
>
> "I got the idea from the production engineering department."

They discuss the location and fixing of the pallet and the positioning of dowels and poka-yoke pin in the base plate. Work rate is very slow, the pins locating the Y axis are in shear and probably won't withstand the clamping force. They are unsure of the orientation of the work coordinate axes. They consider purchasing a cam they think it will take too long to make one. This proposition is extended to bolt on handles for lifting the pallet. Actions are agreed to edit the drawings, making sure there is clearance to machine both ends of the component. They agreed that they need to look again at materials properties.

6th observation Group 1,2,3 & 4, 20th December 2013

The group leader is absent and the two remaining group members use power point to present their proposal. An animated .gif is used to show the action of a cam clamping mechanism. Dimensions are shown but the detail of the kinematic and mathematical analysis of the movement of the mechanism were absent. Their choice of materials is justified by comparing a number of alloy steels on cost and mass. Concept sketches are unsophisticated but clearly show positioning of locators. The Y axis locators on the pallet are in shear and will need to be repositioned. They have used a number of information sources for their research, including websites for tooling and costing calculations and expert opinion for materials and material costs. Project management documents include a Gantt chart with dependencies but there are no updates on actual time expended. They verbally make reference to the project specification. The proposal was costed at £43.7K. I received a request for information dated the 9th December asking for guidance on the type of cam to be used. They provided a drawing from which I provided some general feedback on the proportions and indicate the parts they need to calculate.

6th observation Group 2, 20th December 2013

All group members are present and use power point. They make a confident presentation using concept sketches to illustrate ideas, the later versions are dimensioned. The design idea is related explicitly to the client specification. From several options they have elected to use stainless steel on the basis of cost, machinability and availability and their belief it will meet the specification. Information sources are not cited except the use of the Sandvik website for machining parameters. Apart from basic maths on calculations of mass and speeds and feeds they were unable to justify the mechanics of their design and requested assistance. There is no mention of location, restraint or work axes. Comprehensive project management documentation was largely the work of one group member. A Gantt chart and logbook are presented showing planned work load distribution. tasks are numbered and actual progress has been recorded against planned time. There are no dependencies shown. The risk register detail has improved. Overall proposal costs are now at £28.8K. I received a request for information dated the 13th December asking if one cam will be strong enough to hold the work piece in the pallet, to provide an opinion on the 2 cams holding the pallet to the base plate and to assist them calculating the kinematic analysis

6th observation Group 3, 20th December 2013

All group members are present and use a power point presentation. The first 5 minutes are dedicated to showing a history of the client's company and the purpose of the clients component 'to the client' and they talk across each other rather than delegate specific sections. There is an implicit reference to the specification and a confident explanation that their work-holding system is fast and efficient and 'well within' the loading time and maximum permitted mass. This claim is not proven. A series of concept sketches of 3 different ideas is shown for the pallet but no design of the base plate or the clamping mechanism and no references to location and axes. They have chosen to use Tenzaloy for the fixture but there is no breadth of researched information to support that choice from other possibilities. Their talk through various technical considerations are quite good and an attempt has been made to do a mathematical analysis of the system. The design is currently over constrained due to the use of parallels. Project management is weak and lacks strong organisation. There are no previous versions of the Gantt chart and it shows no dates and no tracking of time expended. To date no documents have been uploaded to the project folder and communication has been via text rather than Gmail as requested. A request for assistance on mechanical analysis was submitted too late to meet this presentation date and after 2 weeks procrastination. Their proposal is costed at £39.1K after 3 iterations and they are unclear as to how this was developed. This group had considered presenting a request for information but procrastinated to the point that they could not have received a reply in time for this presentation date.

6th observation Group 4, 20th December 2013

This group presented a very basic power point of 4 slides. The slides added little to the presentation and they could have presented as good a case without it. The group alluded to the client specification but no development ideas were explicitly related to any points within the specification. Instead of producing concept sketches they developed ideas using solid works drawings. The quality of the drawings was good but needed extensive revision and this impacted on the actual draughting phase which used a different 2D CAD system. Their design employed toggle clamps that were fitted beneath the base plate to lock the pallet and was quite innovative. Their material of choice was EN24 alloy steel, it meets the specification but they haven't said why. The locating pins on the pallet are long at 23mm to accommodate the positioning of a cam for clamping. Their initial clamp idea used threaded pins which they later rejected on the basis the pins would wear. They justify the idea of bolting locators from underneath because it would remove the need for critical machining tolerances. Project management documentation is complete and uploaded to the group project folder but only the Gantt chart was presented. The chart showed a 2 week overrun against planned work. Total proposal cost now stands at £51.3K. This group acknowledged they knew they needed assistance with mechanical analysis but hadn't considered submitting the request.

Draughting Phase 10th January to 21st February 2014

There was noticeably less dialogue between the participants in this phase. Many of the disjunctions result from earlier errors or omissions.

> "The locating pins and cap head bolt locations were changed to eliminate the possibility of fouling with swarf."

A judgement of hypotheticality

> "This week we all worked on calculations, but further work is still needed. A problem occurred with the positioning of the base plate slots so X will re-measure the machine table."

Judgements of factuality and measurement

> "We discovered one of the drawings was not done and we had to complete it for the deadline."

Judgements of practicality and counterfactuality

> "In hindsight making a check list of drawings to be done would have enabled better control of this work phase."

> "We lost time having to revise the cam drawing, we should have identified the problem in the concept drawings beforehand."

A judgement of counterfactuality

> " We need to review the calculations to reduce the margin for error. The positioning of the cam has been reviewed and resolved."

> "The locating block drawing has been edited, to allow tool access for easier machining."

Judgements of hypotheticality, practicality and factuality

> " We tried to solve the forces for the cam but we have had to submit a request for information."

Judgements of factuality and appropriateness

Appendix 17

Case Study 3: Mechanical Design & Sustainability Assignments.

Design of Linear and Rotational Kinematic Linkage.

Phenomenology of Learner Experience, Observations and Descriptions.

2nd observation of Group A and reflective precis, 25th November 2013

> "There is a change to the spec, if we use belts there has to be a tensioner, it will change manufacturing costs and we have to provide the mechanics."
> "We need to decide on using gears or belts with a crank, con rod and slider."

Judgements of practicality and of hypotheticality.

> "Research what best to use for a conrod."
> "We also have to show in the report how the design changed due to the change in spec. Pages 10 and 11 refer on design justification."

A judgement of practicality.

They discuss the dimensioning detail of the base plate and components. Reading through tutor comments on moodle.

> "A belt system is no longer plausible."

Judgements of counterfactuality, the reason for this judgement about a belt system is not clear.

> "Anyway we could avoid using gears, we could use a friction drive with a rubber tyre."

A judgement of hypotheticality.The specification change has forced a change in the way some of the team intend the problem space. It appears that they may have judged gear and belt systems to be to complex. It is not known if that means to complex for them or too much effort for the marks.

Record of reflective precis from one of Group A, 25th November 2013

Who made the most important decision and why do you think it was important?

> "It was a joint decision, to plan in detail before we started the design."

Which of the decisions made by the team did you disagree with and why?

> "The decision to start on the design, we went to planning first because in 1st year the failure to plan was costly. Also we got

lectures on project planning so we expected to get marked on this."

What alternatives were possible?

We considered a variable cone and belt drive but disregarded it, there was a directive from the tutor not to use belts."

What effective/appropriate solutions will result from the decision?

"We managed to keep control of the project through planning and should get out report in time."

2nd observation of Group G, 21st November 2013

The design now shows a cam and linkages, the sketch is detailed even showing exploded view with bolts but the mechanism appears to be kinematically infeasible.

"I don't think this will move this way."
"I think it is fine, it needs a bracket and a spring to keep it in a straight line, at least we have a concept."

Two students considering the operation of their design, one judges it to be conceptually improbable (judgement of discrimination) the other judges it to be appropriate, subject to additional work which is a judgement of hypotheticality.

"Have you done the report?"
"No I didn't have time."

A judgement of instrumentality.

"You can take more time, we've started on the CATIA."

A judgement of counterfactuality.

"We don't have to assemble it, just need an electronic model."
"I need cost and material for manufacturing and sizes to put into the CES software. I don't think forces are needed for the report."
'Yes we do, for strength etc. We need a free body diagram for this."

The students exchange views that rely on several judgements of discrimination, appropriateness, practicality and counterfactuality.

The discussion continues on mechanisms, size, forces and use of a belted system.

"By tomorrow we need some information on free body diagrams. If you can complete this by tomorrow we can book a room in the library it'll take two to three hours."
"Can you scan this? We also need to do a logbook for personnel marks."

This statement is a judgement of practicality only, the students are just acknowledging the assessment criteria. The criteria define some aspect of the problem space for them.

The team discuss marks from a particular tutor (below).

"We all got around 7.5, 7.6 etc why? Did you get 10? In the previous lab we all got 10."

A judgement of causality and a potential intention attribution that the low mark was due to the tutor's agency not their poor performance.

"OK let's drop this topic, book a room in the library for Tuesday."
"What do we need for the next meeting?"
"The free body diagrams."
"Check the belt, crank and slider sizes on the base plate."

Judgements of relevance and composition.

"If we don't have to make the mechanism we can use gears."

A judgement of hypotheticality and practicality.

"Guys according to the Gantt chart we are falling behind."
"It's not that bad."
"We're behind, the deadline is by Xmas."

A rational judgement of measurement and factuality using the Gantt chart data followed by a heuristic judgement of measurement about the amount of time available. The respondent's optimism will underestimate the amount of effort or time a task will take.

"We need to check if it has to be made."
"Check it today?"
"We can look, if we can see it we can adjust for it."
"What if we make a wooden model or foam would be quicker, some group did this last year."
"For forces you need the base plate dimensions to work out your sizes."

Judgements of practicality and of hypotheticality about the necessity to actually make their design.

3rd observation of Group G, 26th November 2013

The team are discussing the distribution of marks in the project assessment criteria.

"We can't use a belt system it's too difficult."

A judgement of counterfactuality

"We can but, need a full explanation and justification."

A judgement of counterfactuality

"Explain the proportions of the gears, the radius and thickness."

A judgement of counterfactuality

"We need to justify everything."

A judgement of counterfactuality

"What about materials? We need a bill of materials."

A judgement of composition and practicality.

> “Looking at the percentage of marks we are behind schedule, don’t
> we have to design the base plate?”

Heuristic judgements of measurement followed by a judgement of hypotheticality

> “Draw it on CATIA but that’ll take time as none of us have good skill
> with CATIA.”

Judgement of appropriateness (capability) and measurement.

> “Need to complete the FAST diagram, when do you want to meet?
> Tomorrow?”

A judgement of hypotheticality.

> “No later today! You know the problem is you haven’t done
> anything!”

Judgement of measurement appropriateness (capability) and intention attribution

> “Tomorrow is better for me.”
> “OK what part do you want to do?”
> “Manufacturing costs, using the CES software.”

At this point two students set to work on the FAST diagram and free body diagram. And two others work on manufacturing costs. The diagram of the motion uses two gears, crank, crosshead and slider. The proportions and relative positing of the components *don't give the impression that the mechanism is feasible.*

Appendix 18

Case Study 3: Mechanical Design & Sustainability Assignments.

Design of Collapsible Engine Hoist.

Phenomenology of Learner Experience, Observations and Descriptions.

1st observation of Group K, 20th January 2014

The students appear to be unfamiliar with the process of FAST diagrams. An exchange of ideas involves putting forward a number of propositions as they explore the problem space. The respondents exercise judgements intending alternative problem spaces. The interaction generates a shared experience of the problem.

> "What about energy dissipation? Is it something we need to think about"
> "If I spray water in your face it isn't warm, it's not going from very high to low pressure."

A proposition is made, the learner having made a judgement of composition about the problem space and the relevance of certain knowledge, followed by a judgement of inference (deductive)

> "It's not very high pressure, pretty high pressure."

> "It's got to be able to create a vacuum to open the non return valve."

A judgement of value, another learner responds with a judgement of hypotheticality.

> "Not really. What's next, it's a cycle."
> "Saying the system is about displacement is non-specific."

A judgement of counterfactuality questioning the validity of the previous judgement

> "I think storage is part of the cycle."

proposal from a judgement of relevance and problem space composition.

> "You can control spray"

A judgement of factuality

> "Yes but it has little bearing on the system other than output. The spray can be adjusted but that's right at the end."

A judgement of factuality

After 20 minutes the tutor intervenes and demonstrates an outline model FAST diagram, i.e. main function, sub function. The students then return to the problem. Students conduct an internet search on spray bottles, the learning is implicit and does not have a particular objective other than looking at types and terminology. Group K discuss a range of attributes for the bottle.

> "It should be easy to clean, smooth to operate, attractive colours and a big tank."

Judgements of composition and relevance

"A big tank will be heavy."
A judgement of hypotheticality

"Different nozzle functions and flow types."
Judgements of composition, relevance

"What about safety?"
Judgements of relevance and practicality

"A safety function in the nozzle?"
"Don't limit to the nozzle."
Judgements of composition, counterfactuality

"A big tank opening so it will be easy to fill."
Judgements of composition, practicality and counterfactuality

"It's not glass, but it can't be attractive if its transparent."
Judgements of discrimination and counterfactuality

"It can be!"
A judgement of counterfactuality

"Need to see through the measuring gauge."
Judgements of composition, hypotheticality

"Easy to lock, a lockable nozzle."
Judgements of composition, hypotheticality

2nd observation of Group K, 11th February 2014

The students are now in the initial stages of the design of their engine hoist and have generated a number of proposals. This team are selecting a design from those proposals.

"Has anyone got a Pugh matrix? Can we narrow it down to 3 from our data?"
"The PM calls for a datum do we select one of our designs?"
"Normally we'd select from a current market product."
The above three are about procedure and as such are judgements of practicality

"What do we select on?"
"Aesthetics, cost, ease of use, ease of maintenance, ease of manufacture, ease of storage (compactability)."
Judgements of hypotheticality

"Is that it?"
"Yeah that's about it?"
Judgement of factuality

"What about X's idea?"
"OK, but chains? they're time consuming to use."
Judgement of appropriateness

"The engine won't just lift out, it'll take some manipulating."
Judgement of hypotheticality and practicality

"It's never just a one person operation you'd always have one other person there, it wouldn't really matter if one had to guide the engine."
A redundant judgement of hypotheticality and instrumentality, the specification requires the unit to be capable of being operated by one person.

"It's not really ideal is it?"
A judgement of appropriateness, a judgement of practicality would have referred to the specification.

"OK let's choose three designs."
The team all contribute importance ratings to the Pugh Matrix Table 3. Discussing the various designs, they recall the need to have a 30° extraction incline as part of the PDS.

Table 3. Pugh Matrix

Cost	8
Ease of Use	7
Ease of Maintenance	5
Ease of Manufacturing	5
Aesthetics	3
Compactability	8

"Shall we include reliability?"
" It's a bit hard to gauge! sort of look at the reliability of most complex parts, how can we know this?"
Judgements of discrimination and factuality

" I suppose it's an educated guess!"
A judgement of counterfactuality

"Is your idea easy to use?"
"I've no idea."
"Telescopics are quite temperamental......could easily break."
Judgements of practicality and hypotheticality (a confabulation)

"Is aesthetics really that important?"
Judgements of value and relevance

"That's why it has a low importance rating!"
A judgement of counterfactuality

They discuss collapsibility, but the drawings do not show how this is achieved without simply dismantling the hoist.

"I think mine's hilariously stable."
"I think mine's stable but not as much as these two."

Heuristic judgements of reference and counterfactuality.

"What factors contribute to stability?"
"The width and length of the base and the mast placement during operation."

Judgements of factuality

"What about reliability?"
"Give it five."

Heuristic judgement of value (importance) for the Pugh matrix.

"I reckon mine is quite reliable, the thing that concerns me about yours is the effort required to operate it."

Heuristic judgements of discrimination and hypotheticality

They complete the Pugh Matrix and total the points for each proposal.

"From the PM analysis X's is the best design."

A judgement of discrimination.

"What about materials? I suggest we use hollow tube/pipe."

Judgements of composition and appropriateness

"We need to get together in the week to go over dimensions."
"Health and safety, free falling or striking someone has to be prevented."
"The safe working load will have to be stated on all parts and we should include any relevant PPE."

Judgements of practicality

3rd observation of Group K, 12th February 2014

The students discuss a concept drawing showing a trolley that rolls under the car with a lift mast and hydraulically operated hoist.

“Hydraulics? Nice sentiment but we need to keep it as cheap as possible,..... a marketing ploy.”

This judgement is in accordance with the PM rating of 8 and the need to keep costs low. It is a judgement of discrimination and hypotheticality.

“We need to wait for G. I’m confused guys I really did 3 drawings, I don’t know where they are.”

One student is sketching an engine and transmission,

“We need to draw out the engine and transmission at 30 degrees, a solid bar would be better than chains.”

Judgements of discrimination and hypotheticality.

“Why 30 degrees?”
“To get the transmission clear of the bulkhead.”

A judgement of practicality, the angle is given in the specification. Without this knowledge this event would appear as a judgement of measurement to an observer.

> “One idea I had was to have a set of rails like this,” referring to a sketch “To pull out the engine and transmission at an angle using a mechanical winch which I know is not ideal but.........”

A judgement of appropriateness about a mechanism followed by a judgement of counterfactuality.

> “3 – 4 free body diagrams with text”
> “How often will people need an engine hoist? I don’t think it needs to be foldable, there’s no intermittent use scenario.”

The specification asks for a collapsible unit. This judgement of appropriateness is redundant.

> “Do the wheels need brakes?”

a proposal from a judgement of composition and appropriateness

> “This is a lot easier than the last project.”

Judgements of reference and discrimination.

> “We got marked down for free body diagrams and calculations last time so...............”

A judgement of factuality, a potential judgement of counterfactuality could not be detected because the statement was interrupted.

> “The FAST diagram is half done.”

Heuristic judgement of factuality and measurement

> “Hard to move a massive engine on wheels.”

Heuristic judgement of factuality.

> "I’ve researched a hydraulic system, next idea use a screw or scissor jack and a motorised version."

Judgements of appropriateness and relevance that may culminate in a judgement of composition about the problem space.

> "We need to decide the market, whether to go expensive or 'bog-standard'."
> "Do we have to decide this now?"
> "No!"

A judgement of relevance that cost should be related to a particular market, the weighting for cost in the Pugh matrix is high and the term ‘cost’ is equivocal. There was no indication whether costs should be kept low or pitched at a particular market.

> "An initial needs analysis is part of the project spec."
> "We need three detailed concepts, as detailed as we can make them."

These are re-statements of project criteria, not judgements.

> "Have you got enough to finish the FAST diagram?"
> "No I need to work out the forces in the system."

A judgement of factuality

> "What's the human input?"
> "Look at the PDS, customer requirements and design parameters."
> "Is this the full 15 steps?"
> "Dunno, need to revisit that lecture, browse project outline for scope of information, product life and durability."

A judgement of factuality

"No meeting notes? Any actions? OK Done."

4th observation of Group K, 24th February 2014

"We've gone with an entirely mechanical system, a rail slide and hoist." - referring to sketch.
"I agree I like this idea."

A judgement of appropriateness.

"The frame has been made specific to one engine, but not all engines have the same features for lifting."

A judgement of counterfactuality

"What about hydraulics?"
"We'll revisit it, it has potential application."

A judgement of appropriateness.

The team conduct a morphological analysis comparing methods of fixing, power systems and moving systems. They discuss a hydraulic power system at some length and the use of manual or electrical power and even a remote control. They opt to use a hydraulic ram and the hoist base has a 'tricycle' format.

"The reason ours looks so much like the others is that there are a limited number of viable solutions!"

This is a heuristic judgement of instrumentality. A lot of their ideas will have been formed after conducting a competitor survey in which there are a limited number of designs on the market. Thinking that these are the only viable ones is a representativeness bias in the judgement.

"Have you spoken with the other teams? The PDS specifically says the solution should be innovative."

A judgement of practicality, the student expresses concerns about the current state of the problem space, essentially leading to a judgement of appropriateness.

"I wonder if they mark this on the method rather than the actual end product?"

An unusual judgement of instrumentality in this proposition, the student intends a state of affairs that if correct means they don't have to be concerned about the outcome thereby justifying the current design and its 'unintentional' similarity to others.

One student is re-sketching the hoist.

"I thought it would be safer and easier to use hydraulics than a screw but now the design looks like many others."

A heuristic judgement of appropriateness and reference.

"Do we need a brake on the wheels? It'll be used on a flat surface."

Appendix 19

Case Study 4: Built Environment Design Integrated Project.

Phenomenology of Learner Experience, Observations and Descriptions.

2nd observation of Group E2, 4th November 2013

The team discuss their proposal for the extension to the John Laing Building. They note they need 2 designs and to date they have only one proposed design.

> “We could make the lifts accessible from both sides,”
>
> “There may be conflict with fire regulations and distances from fire exits.”

A judgement of practicality followed by a judgement of hypotheticality

> “Let’s spread the development over 2 floors and make the whole envelope smaller.”

A judgement of appropriateness and practicality

> “The electric substation should be demolished as required in the project spec.”

A judgement of appropriateness and practicality

> “It’s better to split the offices near to each department because of concerns over traffic density.”

A judgement of hypotheticality and causality

> “We could remove the whole centre for lorry access to the materials lab.”

A judgement of hypotheticality and appropriateness

> “For safety, have one side for carrying traffic and the other side for students, it would also make it easier to manoeuvre the trucks.”

A judgement of practicality, appropriateness and hypotheticality

“The toilets could be put together in one place – cleaner.”

A judgement of practicality, appropriateness and hypotheticality

“What about entirely cubicled mixed toilets?”
“Is there a precedent?”

The respondents question is a judgement of practicality and appropriateness.

2nd observation of Group H24, 4th November 2013

This team are now using CAD software checking the drawing scale and paper space.

“Still trying to figure out how to renovate the ruins.”

“I’ve been playing around with how to extend.....”

“Is that what you’ve been doing with Dropbox?”

“Yea.”

“To keep the character of the building we have to extend it lengthwise.”

A judgement of hypotheticality

“Extend the lecture theatre for access from the other end.”

A judgement of appropriateness

“It makes much more sense to go into the staff car park and double the height of the foyer space.”

Judgements of reference and hypotheticality

At 20 minutes 5 have become passive observers listening to a conversation between 2 others.

“Open office space, integration...........have the PhD room next to the staffroom, using moving partitions. Don’t use glass, we need to reduce noise.”

Judgements of hypotheticality, appropriateness and practicality

“Should there be a communal room?”

Judgement of composition

“Labs should have their own workspace, taking out all the small rooms and have a room for test pieces to dry.”

Judgements of appropriateness and practicality

“Do we extend the Architects room, or leave it where it is?”

> “Move the whole studio and put labs between it and the main building.”
>
> “Keep toilets in the original places.”
>
> “Investigate materials and geotechnical labs and see what rooms are needed for this.”

The above four statements is a series of propositions resulting from judgements of hypotheticality.

> “What about roof access for the lifts? And we need a steel fire escape.”

a proposition from a judgement of hypotheticality and a judgement of practicality.

> “Not sure about the space, why go on the roof in the first place?”

A judgement of factuality.

> “Recycle heating costs too much to put underground.”

A judgement of practicality.

> “Partition the labs to create a corridor access to the exit?”
>
> “We could extend by 2 metres, move the columns and joint new steel work to existing structure? The structural labs have to be extended.”

Propositions from judgements of hypotheticality and practicality

> “I’ll complete the drawing by tonight, then you guys have something to work on!”

3rd observation of Group H24, 25th November 2013

The team are discussing attendance and workload. There are issues regarding input from some team members. One (absent) has claimed that work has been lost due to a laptop being stolen. Other team members doubt that the work was ever done and there are comments about unprofessional behaviour.

> "M is doing the structural calculations is he not in today?"
>
> "Yes, I've got them in portable document format (pdf) by email."

A judgement of factuality

"Were moving the classrooms from one side to the other and extending into the car park."

A decision potentially based upon judgements of appropriateness and hypotheticality

"Someone needs to take over the sustainability work, when he lost it he failed to keep a back up in dropbox. I don't think he'll come up with the work."

A judgement of causality followed by a judgement of hypotheticality

"I've got two concepts one using wood, I wanted the extension to look soft and flowing because the existing building is very straight with columns."

A heuristic judgement of discrimination (perceptual)

"We need 2 ~ 3 images, the original plan was to do it room by room."

"I spoke to the tutor today."

"Do we need to submit AutoCAD files Wednesday?"

"Yes."

" I think that's everything, 2 schemes, facades in pdf one timber and one in steel, very basic."

Judgements of factuality

" I don't agree with the unit, it's not realistic."

A judgement of appropriateness

"I think it's peer reviewed."

A judgement of practicality

"One has never turned up or contributed to the dropbox."

A judgement of discrimination (perceptual)

> "I don't know whether they did or not, they should have been allocated individual tasks."

A judgement of counterfactuality

The following notes were taken from a brief talk with the team. They are near the submission of end stage 4 having corrected formative feedback on their work. Two of the team confirmed that the feedback corrections fit their expectations of omissions or areas in which they thought corrections would occur.

Judgements of counterfactuality. There is a normal tendency to reconstruct memories after the fact according to currently known facts and one's current beliefs. In this way, the individuals making the judgement, construct a past that is more consistent with the present and appearing to be more predictable than it actually was.

Two of the team discuss finishing costs.

> "There needs to be a balance with the environment, like grass with used storage and car park space."

A judgement of appropriateness and analogy

> "Is cladding cheaper? What about glass?"

A proposition arising from judgement of appropriateness

> "We need a solar and thermal analysis."

A judgement of practicality

> "Contracts and referencing."

A judgement of practicality

1st observation of Group N, 12th November 2013

> “Sustainability is nothing to do with the new building, he wants an estimate of the current building efficiency.”

A judgement of relevance and an attribution of intention.

"Carbon energy use in products, look at a website for advice, the rest is strategies for low impact construction."

A judgement of composition and relevance

"What about cost?"

A proposition from a judgement of relevance

"No."

A judgement of composition

"Air conditioning in computer rooms, there's a huge waste there and the heat generated from lights is wasted energy."

A judgement of factuality

"What about the roof? Do we have a green roof?"

Proposition reintroduces (perhaps unintentionally) the need for roof access by lift.

"It impacts on the loading and if there's no access to it how can it be maintained?"

A judgement of factuality and hypotheticality

"We could have a lift going up to the roof."

"It wouldn't need heavy equipment just a trimmer etc."

Judgements of relevance and factuality

"I'll have to check the structural implications."

A judgement of practicality

"What about roof lights?"

"What do you mean? Can I see your model?"

"What about pollution? There are 2 chimneys and there's air conditioning maintenance."

A proposition from judgements of relevance and practicality

"Next meeting is Wednesday at 09:00, if I change the floor plan you'll know then."

"AC telemetry"

"Isn't this a bit in depth for a concept design?"

A judgement of appropriateness

"What about cladding? Tiles or concrete?"

A proposition from a judgement of appropriateness

"No it looks too white."

A judgement of appropriateness and value

"You don't get a fantastic finish with concrete."

A judgement of discrimination (perception)

"Have you seen wood grain impressed from the shuttering?"

A judgement of discrimination (perception)

"We haven't got the structure yet so why worry about the finish?"

A judgement of practicality

"If you use concrete it affects the structure, why don't we just use concrete?"

A judgement of hypotheticality and instrumentality

"Put blinds on the outside of the windows,"

A judgement of practicality

"I'm confused"

Architect draws them on the sketch.

"Support these on the walls, plant some trees."

"Use white mix concrete and attach tiles, plastic or terracotta."

"White concrete isn't cheap, I think these tiles are cheaper."

A judgement of reference and value

2nd observation of Group N, 13th November 2013

"Today we need to get as much team work done as possible."

"Sustainability is almost complete."

"So are building services."

Two judgements of measurement and factuality regarding the degree of completion

"The drawing grid is not uniform, it's not exactly 10 metres."

A judgement of measurement

"Shall we start?"

"I want to wait for N." (N is sole architect in this group)

A judgement of appropriateness

"Can we get measurements on how much of the interior walls are being removed?"

"I think we're removing most of them."

"But I need to estimate costs."

A judgement of practicality and factuality

N is now present and has a proposition for the engineers.

"I have an issue with these stairs."

"They have to be enclosed for fire protection, basically they just need fire doors."

A judgement of practicality

"I might put them at the back of the building."

A judgement of appropriateness

> “Are you aware the grid is not uniform?” Question to architect.

A judgement of measurement

> “Yes I uploaded a new one last night.”
>
> “All my classmates are doing 2 designs.”
>
> “Check it out! I was under the impression it was 2, even in industry they’d do 2.”

A judgement of practicality

> “If you don’t want one then make it “stupidly biased” so that we don’t have to do it.”

A judgement of hypotheticality

> “I’ve only changed one thing in the floor plan.”
>
> “What's that?”
>
> “For the hydraulics lab, moved the elevator to the foyer.”

The group are now working independently on subtasks. The architect is explaining various changes to the structural engineers about the lecture theatre columns going one floor down. One team member is browsing for information on the web about Breeam Criteria on sustainability.

> “The criteria aren’t recognised. They’re a bit rubbish, not necessarily relevant, just tick boxes, easy to achieve excellence ratings.”

A judgement of appropriateness, relevance and factuality

> “The report for the project requires inclusion of this guide.”

A judgement of practicality about the project specification

> They discuss the positioning of the elevators.
>
> “I could move the staircases to the other side and turn them. This elevator at the Crossman building end can go to the roof.”

A proposition based on judgements of hypotheticality

“Do you have a fixed distance?”

“No.”

“OK it allows us to have more deflection on the beams.”

A judgement of practicality

“Put the stairs here and move these columns, can I have a balcony here to justify that?”

A proposition based on a judgement of hypotheticality

“We’d need to see if the additional load on the existing foundations is acceptable.”

A judgement of practicality

“If we use the existing foundations we have to prove our design by calculation.”

A judgement of practicality

“Just move the stair so that I can visualise the whole thing. If we didn’t need those columns there what to do with this open space?”

“If we move the columns to the edge we load the existing foundations which we don’t have calculations for!”

A judgement of hypotheticality and factuality

“Have you seen Herbert? What if we use timber beams instead of concrete? It looks better than steel.”

A judgement of hypotheticality and value

“What about King’s Cross Steelwork?"

“I have to admit that’s nice.”
“So where do you want the timber then? Have you got a 3D model yet?”

“Partly, I’ve moved the stair. The problem with timber is that it moves, not as much as steel though.”

A judgement of reference

“It can be finished how you like, if we can use timber we will.”

“How thick is the floor slab?”

“Minimum 120 to 175 off the top of my head, worst case is 225.”

A judgement of reference and measurement

“Clarify the view of the building for new and existing floor levels.”

“Why’s the roof sloping that way?”

“I didn’t want it to look like a box, also the south face slopes away for shade and solar gain.”

A judgement of instrumentality

“How big has the concrete lab got to be?”

“ About 100 metres square.”

A judgement of reference and measurement

“If this becomes the concrete lab then this whole area becomes free, is that OK?”

A judgement of hypotheticality

“What is it for?”

“The plant room.........put storage in the ends move the cleaner’s cupboard and student work room, storage and work room.”

A judgement of instrumentality

“We need 15 metres square of office per lab.”

A judgement of practicality and measurement

“The winning proposal last year used a key for rooms, shall we?”

“Yes”

A judgement of practicality

> “The admin, offices and reception are they too little or too big?

3rd observation of Group N, 18th November 2013

The initial focus of discussion in this meeting is costing and quantities. Firstly they considered furniture and the lecture theatre and toilets. They then move on to look at materials which includes structural steel, concrete, timber, plastic boards, and glass. The discussion then moved to building services and ventilation from the floor. The positioning of stairs for circulation and fire prevention crops up again.

> "The lift shafts aren't structural, it depends on us." Observation by structural engineer.

A judgement of factuality and practicality

> "OK then let's have them structural."

A judgement of practicality

> "Can you work out a loading for the foundation pad and the size of the foundation slab for costing?"

The discussion turns to assessment requirements.

> "What's needed on the poster?"
>
> "Floor plans, key BIM aspects, photos of the site plan, architectural design issues, the drawings in A3."
>
> "The submission has to be two A1 posters in one file but split for marking."

Judgements of practicality and composition

> "OK that clarifies my position. Work loading is a problem as I'm the only architect in this group compared to the others."

Judgements of discrimination and measurement

> "For sustainability we just need some references and a plan for sustainability."

Judgements of practicality and composition

> "I think structural have considered the weight of people on beam 1 not beam 2."

Judgements of inference

> "Is this a column or a beam?"
> "This is in plan view"
>
> "I'll price as a beam irrespective of size."

Judgements of analogy

> "Won't it be overpriced if you assume 10 metres? The cantilevers are only 1.5 metres long!"

A judgement of measurement and value

4th observation of Group N, 27th November 2013

The team have been missing one member for 6 weeks and they are discussing the potential impact. They agreed it has little effect on the current stage but that individual is the person with most REVIT capability and they are aware that it will impact stage 3 severely if he doesn't re-engage.
In this short discussion the most prominent judgements were of counterfactuality, measurement and causality and a judgement of hypotheticality.

They consider the need to involve the course tutor. They have heard they only need to submit one architectural design. The whole team are working independently on parts of the report and need to complete these by next week for stage 2. The time management pressure is driven by the assessment deadline rather than the project context. The architect likes the poster layout but thinks some of the colours are a bit too bright.

> "What structure do you put in the poster?"
>
> "It depends what they want."
>
> "The design includes the structure layout, so refer to the assignment criteria to determine the division of the page."

A judgement of practicality and instrumentality

"There's not enough space for all three floor plans."

A judgement of measurement

"We know what has to go on but how to present it so that it looks good?"

A judgement of composition and a proposition to a judgement of translation

"An elevation from each side is good and maybe a section if there's room."

A judgement of composition

"Any space that's left maybe a 3D mass model? I want to do a 3Dmass model."

A judgement of appropriateness and relevance

"The calculations takes a whole page for one beam."

A judgement of instrumentality

"Portrait or landscape? I think the way they've done it looks good."

"They said two A1's guys so we'll stick to that!"

A judgement of instrumentality

The discussion reverts to structural issues.

"Why are we piling?"

"The reason we are using piles is because a solid pad won't go deep enough to reach solid rock."

A judgement of instrumentality

"Need to look at least 3 metres down to reach sandstone."

A judgement of measurement and inference

"What about soft soil mechanics?

"Not at this stage, I'd say 8 metres so if we piled to 10metres?"

A judgement of measurement and inference

"Their response might be to challenge the piling depth but we can justify it."

A judgement of hypotheticality

"By close of play today you need all the input to the poster from everyone?"
"Yes."

"So from us three you just need bullet points."

5th observation of Group N, 20th January 2014

2 of the team are working on the presentation and 2 more are using REVIT.

"Do we redesign now or at the next stage?"

"Now we are just looking at potential changes, we can decide to change later."

A judgement of appropriateness

"The software will tell us what we have done well, or not well."

A judgement of practicality

"The less we have the better it looks I think."

A judgement of value

"Where is the feedback for all of us?"

"In dropbox under admin."

"This stair case faced the other way, there was no way to get to them so I put a door in there."

A judgement of counterfactuality and instrumentality

"Make this 1.2 metres so there is enough room to get by."

A judgement of measurement

"It depends if building regulations permit it."

A judgement of practicality

"You see those windows, the way we changed it? I don't think there should be windows in the fire exit! It should be sealed!"

A judgement of practicality

"What were the problems?"

"No railings, I've moved this partition."

"Is this a corridor? There's meant to be a void here?"

"No, there is a glass wall here, the void is here."

A judgement of factuality

"I've fixed the roof level so these walls are now correct."

"Is the lecture theatre OK?"

"It's down here."

"OK so the walls actually fit now."

A judgement of factuality

"This slab needs to be tilted down."

A judgement of discrimination

"Go here?"

"Yes." Architect uses a sketch to illustrate the shape and attitude of the slab.

Two of the team are viewing a Powerpoint of comprehensive cues from the tutor on the scope of the evidence required for the presentation. One student is writing up a BIM reflection and their administrative processes. One other is revising the drawing, removing columns and extending walls, checking the spacing between the structural and architectural models.

> "Just put another row of columns here."
>
> "Won't that totally screw up everything? - Move these?"
>
> (Architect) "No! They will wind up in the middle of the lecture theatre. The columns fine it's just the wall."

Judgements of hypotheticality and appropriateness

6th observation of Group N 20th January 2014

> Four of the team are writing up the introduction to their report and using data from Revit and Solibri, their justification is the relative simplicity of this software as a BIM tool.

A judgement of reference about the software.

The software shows any design clashes and they can take off data for costings in stage four of the project. The students are also making 3D scans of the building and providing a written explanation of various features.

> "Do we need to use bullet points? It may be better than waffling and easier to read."

Judgements of reference and appropriateness

> "They may be less irritated and more disposed to give us better marks."

Attributions of intention

A student is using IES software for an environmental survey. The model is missing the upper floor and the roof.

> "Why is the model incomplete?
>
> "IES ignores any areas of the model with errors in Revit. It does too much really, the whole process can take hours and if you find an error you have to back track. It has good data export for sizes, areas though."

A judgement of counterfactuality

> One team member is reading through the assessment criteria.
> "What does this mean?"
> "The reason is we've been asked to do it. There is more about why we've done BIM than other detail."

A judgement of composition

> The Architect in the team is using Revit and notes that the automated function 3D extrusions are not always correct. One other is checking the model for anomalies on Solibri.
> "The floor slab is lower than the support columns."

A judgement of value and factuality

> "We should have sorted this before now, the structural engineers and architect could have seen this."

Judgements of counterfactuality

> "The architects and structural models are done separately."

A judgement of instrumentality

Appendix 20

Case Study 4: Built Environment Design Integrated Project.

Phenomenology of Learner Experience, Observations and Descriptions.

Semi-structured Interview 1.

This interview was with a volunteer from team N on the 10th February 2014. The interviewee had taken responsibility for the BIM coordination of his team project. My questions and analysis are italicised and the respondents dialogue is indented.

"What are you working on?"

> "Building Information Management."

"Can you tell me what that entails?"

> "BIM seems to have different meanings, we use it in modelling. This can be quite complex but it aids mutual understanding."
> "If you look at project management, the architect and the structural engineers may be working on different aspects at different times. BIM highlights issues and generates reports that can be acted on. Also because you can see the process it helps make some decisions."

A judgement of hypotheticality

What kind of decisions?

> "There are lots of face to face discussion issues and the Solibri output picks up the clashes."

"Has anything particular occurred?"

> "The Architectural Technician was ill and the Architect, assisted by one other has had to stand in for them. This resulted in a lot more discussion, management difficulties and clashes in understanding."

A judgement of causality and instrumentality

> "In stage 4 it will be interesting to see if the collaboration continues."

"What is your prediction?"

> "3 ~ 4 will, the cross disciplinary nature of the project will enable less clashes."

A judgement of hypotheticality

> "At this stage the architect is taking on faith any structural issues."

An attribution of intention and judgement of inference

"Will the architect have to compromise?

> "The Architect wanted a lot of cladding or to include something that would give a unique 'brand' image like a roof garden, and a sloping roof but that drives up structural loads and costs"

An attribution of intention and judgement of hypotheticality

> "In other cases the structural team have accommodated their design ideas."

A judgement of counterfactuality

"What about BIM organisation?"

> "That's relatively easy, the main issue is when people don't respond. otherwise its good for organisation."

A judgement of value and counterfactuality

> "If it gives them direction then most can get on with their tasks."

A judgement of hypotheticality

> "Formatting and different computer systems is a problem, could have used notepad plain text."

"What do you think of the workload share?"

> "Some do additional work, I haven't done as much but spent time organising the team. I feel I had to prompt some of them."

A judgement of value and counterfactuality

Semi-structured Interview 2

This interview was taken with same volunteer from team N on the 14th May 2014. My questions and analysis are italicised and the respondents dialogue is indented.

Tell me about the project and how you think it went.

> "The re-design concept is very simple, all the real problems evolved during the project."

A judgement of reference and counterfactuality. (If the notion of simplicity is based on recollection of effort it is a judgement by analogy)

> "I think there was too much emphasis on BIM, its use has grown in industry recently."

'Why's that?"

> "Simplification, clarification, It saves money and time, you can deal with problems sooner. Don't know what the next evolution will be."

A judgement of reference and counterfactuality

"What about accountability?"

> "I hadn't thought of that."

"What about the processes? Were there any constraints?"

> "With sketches we can visualise problem outlines like having to use the ruins relatively quickly."

A judgement of counterfactuality

"Where there any major issues?"

> "A couple, the structural engineers coping with complex structures wanted a minimalistic structure. The architect however wanted more architecturally pleasing designs and was annoyed on two occasions by the limitations imposed by the engineers. More time was needed for extravagant designs."
>
> "Basically the structural engineers were very much opposed to dealing with complex geometry so the compromise tended to structural simplicity."

The respondent makes a judgement of counterfactuality about the tensions between the engineers and the architect. The conflict between producing aesthetically pleasing structures and the need for the engineers to be able to cope with the demands of a *complex problem space would have produced some useful disjunctures with the opposing factions having to re-assess their values in order to reach compromise. It appears from this testimony that the architect found this difficult. A judgement of instrumentality is made about time constraint.*

> "The architect was very resistant and would have taken a strong counter argument to change."

An intention attribution about the architect's judgement of factuality

> "It would have been interesting if the architectural technician had been around earlier, he may have sided with the architect. The project would have been much harder and there would have been a lot more disagreement."

A series of judgements of hypotheticality

> "The team was driven by strong personalities."

Judgements of causality and intention attribution

"Was cost an issue?"

> "It doesn't have a great impact at that stage, extra costs evolved from discussion like the moving of rooms."

A judgement of counterfactuality and a judgement of causality

> "Stage 3 BIM brought in costs."

"Was anything sacrificed for costs?"

> "Maybe not on cost alone, for example we considered an underground car park and the energy efficiency team members were thinking about having 'sun pipes'.

A judgement of counterfactuality i.e. there wasn't sufficient evidence for cost to be causal.

> "The building services guy suggested using an environmentally friendly boiler and recycled materials."

A judgement of counterfactuality about the building services engineer. It is not clear whether this is also a judgement of appropriateness about the engineers judgements.

> "The costs of various schemes ranged from about £7.7m at the lower end up to £12m, some of the facades were too hard to design structurally."

A judgement of measurement and reference.

"How do you feel about the assessment of the project?"

> "1 or 2 thought we were having to jump through hoops, we couldn't use much of the building service engineers expertise."

A judgement of counterfactuality

> "The BIM is basically project management, condensing admin and connecting the right stuff."

A judgement of composition and analogy

> "They left a lot of open space for us to submit our own stuff with little guidance on what they wanted."

A judgement of counterfactuality. The project specification actually runs to 19 pages and just over 6000 words. Learners are free to design what they like but the project brief is comprehensively detailed with regard to how the project will be managed, the tools and how they are to be used and the scope of assessable content.

> "It didn't feel that they'd looked at the Project Execution Plan, they kept asking for it but didn't look at it."

A judgement of counterfactuality. The Project spec refers to the PEP in several stages, it is only specifically assessed in stage 1.

> "The weighting of the assessments mean that students put more effort into high credit modules."

A judgement of hypotheticality and value

> "There's a timing tension with submission deadlines similar to real life balance and organisation of time. A lot of people focus on marks."

A judgement of hypotheticality

> "Speaking to 'A Tutor' they try to plan to avoid issues. Some people are timid and try to avoid conflicts."

Judgements of discrimination and intention attribution

"Was there anything significant in this regard?"

> "Nothing really bad, the criteria are a bit cloudy but it's really good for conflict resolution. The structural engineers are logical but the architects less so."

A judgement of value and of hypotheticality followed by a judgement of discrimination

"Was there anything unexpected?"

> "Jumping through hoops, some stuff was not needed and not marked."

A judgement of counterfactuality.

"Do you think you needed more or less guidance?

> "It was fine just clarity was the issue."

Judgements of discrimination

Semi-structured Interview 3.

This interview was with a volunteer from team H24 on the 22nd January 2014. This interviewee had taken responsibility for the BIM coordination of their team. The student is quite despondent, in his view the project is not going that well and he's unhappy with the effort of some in the team. He talked at length with virtually no prompting. My questions are italicised and the respondents dialogue is indented.

" So how is the project going to date?"

> "The project work gets done at the last minute."

A judgement of counterfactuality. It may appear to be so but most probably underestimates the amount of cognitive effort that precedes any action.

> "We're worried about the relevance of some of it, the focus seems to be on how to use it rather than an evaluation."

As the respondent stated, a judgement of counterfactuality

> "Had to spoon feed a lot of them and I had to chase a lot of people for BIM coordination. Some did very little and then thought the peer assessment was harsh, I thought it was realistic."

A judgement of counterfactuality. People are aware of their own exertions while that of others is not always visible. In hindsight individuals underestimate the contribution of *others and overestimate their own contributions. The others may have intended the role of BIM coordinator as a chaser.*

> "I've been on mini placements and the report feedback is constructive, not sugar coated. We've discussed the future value of critique."

A judgement of appropriateness

> "I felt I was the only one who did the leg work. I think our group was more stable than most though, one group hadn't run any BIM software and the architect dropped out."

A judgement of counterfactuality followed by judgements of causality and reference.

> "There was a great reliance on the BIM coordinator, a lot of the things that kept cropping up came from the structural engineers. They presented more arguments than solutions."

A judgement of counterfactuality and discrimination

> "Solibri was very easy to use but we had a lot of issues, around 500 errors, mainly clashes due to lack of experience with Revit."

A judgement of measurement and judgement of causality

> "Probably a lack of leadership or direction."

A judgement of causality

Semi-structured Interview 4.

This interview was with the same volunteer from team H24 on the 22nd January 2014. My questions and analysis are italicised and the respondents dialogue is indented.

> "There were 8 in our group, 1 architectural technician, 1 building quantity surveyor, 3 civil engineers, 1 structural engineer 1 architect and 1 building services engineer."

> "We had a very good result, I was overwhelmed."

Judgements of counterfactuality

> "At stage 2 my mark was 69% with peer assessment of 77%. Some teams got 37 - 40% but probably didn't have a very good BIM coordinator."

Judgements of measurement, discrimination and reference followed by a judgement of causality.

> "Peer assessment is an important issue, those that didn't do much got their scores bumped up from other's work."

Judgements of counterfactuality

> "The module is not well planned, it's fragmented, there's too much going on."

Judgements of counterfactuality, composition and relevance
"Was there a focus on BIM?"

> "Yes, I handed in a 30 page report for stage 3, at stage 5 it was 50% of the mark."

Judgement of value and measurement

> "The surveyors did very well."

> "There was some lack of motivation, the sustainability report on the lost lap top."

Judgements of counterfactuality

> "I've a feeling that the tutor didn't like out design."

Judgements of counterfactuality and intention attribution

"Where there any budget constraints?"

> "No but there was an implicit cap on the refurbishment of around £8m - £9m."

Judgement of inference

"How was the solution?"

> "Don't really know, the design was left to the architects. The building sequence was to do the new block first then the refurbishment."

> "The emphasis on BIM was too much. If you read the project that is the main goal, the other is coming in too low. I didn't know how much of a task the BIM was but it wasn't as stressful as the final submission."

Judgements of value and instrumentality and reference.

"Do you think effort or behaviours were affected by the marks?"

"It was a 20 credit module and it should have been higher, I'd have been satisfied if it was around 30."

Judgement of value

"Stage 3 flushed out the workers, 75% of it was BIM coordination. The motivation of others was tentative. It caused a lot of tension in some groups."

Judgements of counterfactuality and causality

"What other design options were considered?"

"We extended into the car park the other option was to adjoin to the Crossman Building."

"What about incorporating the ruins?"

"The winning group did that, they won by a flawless presentation, their design wasn't that spectacular."

Judgements of counterfactuality

"We haven't dealt with enclosures before."

A judgement of instrumentality

"Would you have changed anything about the design?"

"I liked the idea of a balcony and double height space. The extension idea was very simple, a zinc roof with an arch and double height space."

"On the structural side we didn't want generic parallel beams in the design."

Judgements of appropriateness

"Any final comments?"

"I didn't like the project, there was too much to do for few credits. It wasn't a refurbishment project."

Appendix 21

Ethics Approval Documentation for the collection and processing of research subject data.

Project Title

A study on Activity Led Learning and the development of judgement capacity in work based learning environment

Comments

Comment	Posted
The research subjects are identified in research records by an identity number. The informed consent forms detailing the identity of the research subject and the ID number is known only to the researcher and kept in a locked repository remote from the research location and subjects or any other persons who will see the research data. The organisation for which they work is not identified explicitly in any papers or research documentation.	Howard Igarashi 12/07/2013 10:41 AM
The informed consent mechanism will be explained to the research subjects and require their signatures and that of the principal researcher and where possible an independent witness on 2 separate documents referenced by a unique reference number. The consent forms will be kept securely, remote from the research site so that data cannot be attributed to any individual research subject by any other third party. The research subjects will be allowed to withdraw from the study at anytime up until 14 days after the completion of the study and any individual data pertaining to them will be destroyed.	Howard Igarashi 12/07/2013 10:44 AM
The research subjects are adults employed by a company in whose normal business they are undertaking a programme of study and enrichment as part of an apprenticeship in normal working time. The principal researcher (H Igarashi)is the consultant engineering tutor for the group and has the agreement of the employer and the research subjects to collect the data as part of usual progress recording and evaluation. The learners may opt out of having their progress on the course included in the research data collection at any time without prejudice.	Howard Igarashi 12/07/2013 10:38 AM
Needs a copy of your research instruments: e.g. observation form, interview design.	John Davies 11/06/2013 08:55 AM
Remove your pre-loaded signature from the consent forms. Indicate the topics that will be covered in the interviews.	John Davies 12/07/2013 04:06 PM
Duplicate H&S document unable to delete but both documents	Howard Igarashi

are identical.	12/07/2013 04:27 PM
Approved and finalised with the permission of the Faculty Leader Ray Farmer.	Joel Gibbs 23/08/2013 11:55 AM

REGISTRY RESEARCH UNIT

ETHICS REVIEW FEEDBACK FORM

(Review feedback should be completed within 10 working days)

Name of applicant: Howard Igarashi ....

Faculty/School/Department: [Faculty of Engineering and Computing] Civil Engineering, Architecture and Building ....

Research project title: Activity-Led Learning, the journey from new student to new professional, and the development of judgement capacities

Comments by the reviewer

1. Evaluation of the ethics of the proposal:

low risk. All participant notification to be followed.

2. Evaluation of the participant information sheet and consent form:

Fine - all seems OK.

3. Recommendation:

(Please indicate as appropriate and advise on any conditions. If there any conditions, the applicant will be required to resubmit his/her application and this will be sent to the same reviewer).

X	Approved - no conditions attached
	Approved with minor conditions (no need to re-submit)
	Conditional upon the following – please use additional sheets if necessary (please re-submit application)
	Rejected for the following reason(s) – please use other side if necessary
	Not required

Name of reviewer: Anonymous ....

Date: 03/06/2013...

Coventry University ETHICS

Medium - High Risk Research Ethics Approval

Where human participants involved in the research and/or when using primary data - Staff (Academic, Research, Consultancy, Honorary & External), Students (Research & Professional degrees) and Undergraduate or taught Postgraduates directed to complete this category of risk.

Project Title

Activity Led Learning, the journey from new student to professional and the development of judgement capacity

Record of Approval

Principal Investigator

I **request an ethics peer review** and confirm that I have answered all relevant questions in this checklist honestly.	X
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	X

Name: Howard Igarashi ....

Date: 26/05/2013 ....

Student's Supervisor (if applicable)

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Name: John Davies ....

Date: 12/07/2013 ....

Reviewer

Date of approval by anonymous reviewer: ....

Medium to High Risk Research Ethics Approval Checklist

1 Project Information

Project Ref:	P13954
Full name:	Howard Igarashi
Faculty:	[EC] Faculty of Engineering and Computing
Department:	[CM] Civil Engineering, Architecture and Building
Module Code:	
Supervisor:	John Davies
Project title:	Activity Led Learning, the journey from new student to professional and the development of judgement capacity
Date(s):	01/09/2013 - 31/07/2014
Created:	26/05/2013 13:45

Project Summary

A PhD project researching the development of judgement capacity in undergraduate students in engineering disciplines

Names of Co-investigators (CIs) and their organisational affiliation:	None
How many additional research staff will be employed on the project?	0
Names and their organisational affiliation (if known):	Not applicable
Who is funding the project?	Coventry University
Has the funding been confirmed?	Yes
Code of ethical practice and conduct most relevant to your project:	

2. *Does this project need ethical approval?*

Questions	Yes	No
Does the project involve collecting primary data from, or about, living human beings?	X	
Does the project involve analysing primary or unpublished data from, or about, living human beings?	X	
Does the project involve collecting or analysing primary or unpublished data about people who have recently died other than data that are already in the public domain?		X
Does the project involve collecting or analysing primary or unpublished data about or from organisations or agencies of any kind other than data that are already in the public domain?		X
Does the project involve research with non-human vertebrates in their natural settings or behavioural work involving invertebrate species not covered by the Animals Scientific Procedures Act (1986)?[2]		X
Does the project place the participants or the researchers in a dangerous environment, risk of physical harm, psychological or emotional distress?		X
Does the nature of the project place the participant or researchers in a situation where they are at risk of investigation by the police or security services?		X
Does the project involve the researcher travelling outside the UK?		X

3 *Does the project require Criminal Records Bureau checks?*

Questions	Yes	No
Does the project involve direct contact by any member of the research team with children or young people under 18 years of age?		X
Does the project involve direct contact by any member of the research team with adults who have learning difficulties?		X
Does the project involve direct contact by any member of the research team with adults who are infirm or physically disabled?		X
Does the project involve direct contact by any member of the research team with adults who are resident in social care or medical establishments?		X
Does the project involve direct contact by any member of the research team with adults in the custody of the criminal justice system?		X
Has a Criminal Records Bureau (CRB) check been stipulated as a condition of access to any source of data required for the project?		X

If you answered **Yes** to **any** of these questions, please:

- Explain the nature of the contact required and the circumstances in which contact will be made during the project.

[2] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

The research will be conducted by overt non-participant observation of undergraduate student groups in the engineering faculty of Coventry University. Data will be collected by non-participant observation, student reflective precis on project work, self efficacy surveys and there will be limited contact with selected individuals or focus groups for purposes of interview.

4 Is this project liable to scrutiny by external ethical review arrangements?

Questions	Yes	No
Has a favourable ethical opinion been given for this project by an external research ethics committee (e.g. social care, NHS or another University)?		X
Will this project be submitted for ethical approval to an external research ethics committee (e.g. social care, NHS or another University)?		X

5 More detail about the project

What are the aims and objectives of the project? To observe and collect data on learners in Activity Led Learning environments in undergraduate engineering disciplines to examine how the learner develops the capacity for judgement through Activity Led Learning.
Briefly describe the principal methods, the sources of data or evidence to be used and the number and type of research participants who will be recruited to the project. Non-participant ethnogrpahic observation and recording of student activity and responses in Activity Led Learning opportunities. Preliminary discussions on method and integration with current ALL practice have been discussed and agreed with faculty staff include Dr C Lambert, Dr J Shuttleworth, Dr S Austin, Dr L Read, Mr Paul Green. The approximate number of students recruited is currently unknown but it is hoped to involve 1st 2nd and 3rd year cohorts from Mechanical & Automotive, Aerospace and Computing Science and 3rd year students from Construction and Built Environment. Approximately 500-600
What research instrument(s), validated scales or methods will be used to collect data? Non-participant ethnogrpahic observation and recording using a log sheet. Brief self-assessment of learning opportunities by student written response and 1 to 1 recorded and transcribed interviews with selected students.
If you are using an externally validated research instrument, technique or research method, please specify. None
If you are not using an externally validated scale or research method, please attach a copy of the research instrument you will use to collect data. For example, a measurement scale, questionnaire, interview schedule, observation protocol for ethnographic work or, in the case of unstructured data collection, a topic list.

6 *Confidentiality, security and retention of research data*

Questions	**Yes**	**No**
Are there any reasons why you cannot guarantee the full security and confidentiality of any personal or confidential data collected for the project?		X
Is there a significant possibility that any of your participants, or people associated with them, could be directly or indirectly identified in the outputs from this project?		X
Is there a significant possibility that confidential information could be traced back to a specific organisation or agency as a result of the way you write up the results of the project?		X
Will any members of the project team retain any personal or confidential data at the end of the project, other than in fully anonymised form?		X
Will you or any member of the team intend to make use of any confidential information, knowledge, trade secrets obtained for any other purpose than this research project?		X

If you answered **No** to **all** of these questions:

- Explain how you will ensure the confidentiality and security of your research data, both during and after the project.

Collected data on group activities will not be attributable to or identifiable to any particular individual. Groups will be indentified by cohort and discipline only. Individuals will only be identified by an ID number in the data and similarly, those recruited for 1:1 interviews will be guaranteed anonymity for their responses. Their identities need not be recorded for the purposes of the information gathering. All data will be stored securely off site by the principal researcher. Data will only be held for as long as it is required to conduct the analysis.

If you answered **Yes** to **any** of these questions:

- Explain the reasons why it is essential to breach normal research protocol regarding confidentiality, security and retention of research data.

7 *Informed consent*

Questions	**Yes**	**No**
Will all participants be fully informed why the project is being conducted and what their participation will involve and will this information be given before the project begins?	X	
Will every participant be asked to give written consent to participating in the project before it begins?	X	
Will all participants be fully informed about what data will be collected and what will be done with these data during and after the project?	X	

Will explicit consent be sought for audio, video or photographic recording of participants?	X	
Will every participant understand what rights they have not to take part, and/or to withdraw themselves and their data from the project if they do take part?	X	
Will every participant understand that they do not need to give you reasons for deciding not to take part or to withdraw themselves and their data from the project and that there will be no repercussions as a result?	X	
If the project involves deceiving or covert observation of participants, will you debrief them at the earliest possible opportunity?	X	

If you answered **Yes** to **all** these questions:

- Explain briefly how you will implement the informed consent scheme described in your answers.
- Attach copies of your participant information leaflet, informed consent form and participant debriefing leaflet (if required) as evidence of your plans.

A consent form and copy will be provided for the signature of each participant and the researcher, the subject will recieve a copy. They will be identified only by a reference ID. ID lists will be held only by the researcher in a secure off site repository. A participant information document will be provided to each subject setting out the purposes of the research, the individuals rights to anonymity and rights to withdraw.

If you answered **No** to **any** of these questions:

- Explain why it is essential for the project to be conducted in a way that will not allow all participants the opportunity to exercise fully-informed consent.
- Explain how you propose to address the ethical issues arising from the absence of transparency.
- Attach copies of your participant information sheet and consent form as evidence of your plans.

8 Risk of harm

Questions	**Yes**	**No**
Is there any significant risk that your project may lead to physical harm to participants or researchers?		X
Is there any significant risk that your project may lead to psychological or emotional distress to participants or researchers?		X
Is there any significant risk that your project may place the participants or the researchers in potentially dangerous situations or environments?		X
Is there any significant risk that your project may result in harm to the reputation of participants, researchers, their employers, or other persons or organisations?		X

If you answered **Yes** to **any** of these questions:

- Explain the nature of the risks involved and why it is necessary for the participants or researchers to be exposed to such risks.
- Explain how you propose to assess, manage and mitigate any risks to participants or researchers.
- Explain the arrangements by which you will ensure that participants understand and consent to these risks.
- Explain the arrangements you will make to refer participants or researchers to sources of help if they are seriously distressed or harmed as a result of taking part in the project.
- Explain the arrangements for recording and reporting any adverse consequences of the research.

9 Risk of disclosure of harm or potential harm

Questions	**Yes**	**No**
Is there a significant risk that the project will lead participants to disclose evidence of previous criminal offences or their intention to commit criminal offences?		X
Is there a significant risk that the project will lead participants to disclose evidence that children or vulnerable adults have or are being harmed or are at risk of harm?		X
Is there a significant risk that the project will lead participants to disclose evidence of serious risk of other types of harm?		X

If you answered **Yes** to **any** of these questions:

- Explain why it is necessary to take the risks of potential or actual disclosure.
- Explain what actions you would take if such disclosures were to occur.
- Explain what advice you will take and from whom before taking these actions.
- Explain what information you will give participants about the possible consequences of disclosing information about criminal or serious risk of harm.

10 Payment of participants

Questions	**Yes**	**No**
Do you intend to offer participants cash payments or any other kind of inducements or compensation for taking part in your project?		X
Is there any significant possibility that such inducements will cause participants to consent to risks that they might not otherwise find acceptable?		X
Is there any significant possibility that the prospect of payment or other rewards will systematically skew the data provided by participants in any way?		X
Will you inform participants that accepting compensation or inducements does not negate their right to withdraw from the project?		X

If you answered **Yes** to **any** of these questions:

- Explain the nature of the inducements or the amount of the payments that will be offered.
- Explain the reasons why it is necessary to offer payments.
- Explain why you consider it is ethically and methodologically acceptable to offer payments.

11 Capacity to give informed consent

Questions	**Yes**	**No**
Do you propose to recruit any participants who are under 18 years of age?		X
Do you propose to recruit any participants who have learning difficulties?		X
Do you propose to recruit any participants with communication difficulties including difficulties arising from limited facility with the English language?		X
Do you propose to recruit any participants who are very elderly or infirm?		X
Do you propose to recruit any participants with mental health problems or other medical problems that may impair their cognitive abilities?		X
Do you propose to recruit any participants who may not be able to understand fully the nature of the research and the implications for them of participating in it?		X

If you answered **Yes** to **any** of the **first four** questions:

- Explain how you will ensure that the interests and wishes of participants are understood and taken in to account.
- Explain how in the case of children the wishes of their parents or guardians are understood and taken into account.

12 Is participation genuinely voluntary?

Questions	**Yes**	**No**
Are you proposing to recruit participants who are employees or students of Coventry University or of organisation(s) that are formal collaborators in the project?	X	
Are you proposing to recruit participants who are employees recruited through other business, voluntary or public sector organisations?		X
Are you proposing to recruit participants who are pupils or students recruited through educational institutions?		X
Are you proposing to recruit participants who are clients recruited through voluntary or public services?		X
Are you proposing to recruit participants who are living in residential communities or institutions?		X
Are you proposing to recruit participants who are in-patients in a hospital or other medical establishment?		X
Are you proposing to recruit participants who are recruited by virtue of their employment in the police or armed services?		X

Are you proposing to recruit participants who are being detained or sanctioned in the criminal justice system?		X
Are you proposing to recruit participants who may not feel empowered to refuse to participate in the research?		X

If you answered **Yes** to **any** of these questions:

- Explain how your participants will be recruited.
- Explain what steps you will take to ensure that participation in this project is genuinely voluntary.

The research participants will be recruited through the CAB, Aerospace, Computing and Automotive and Mechanical departments of the engineering faculty at Coventry University with the approval of the heads of department and lecturers of the departments concerned. The subjects will have the research explained to them and their voluntary cooperation enlisted. Any student may refuse to participate without prejudice and may also withdraw at any time within the agreement of the participant briefing document and informed consent form.

13 On-line and Internet Research

Questions	**Yes**	**No**
Will any part of your project involve collecting data by means of electronic media such as the Internet or e-mail?		X
Is there a significant possibility that the project will encourage children under 18 to access inappropriate websites or correspond with people who pose risk of harm?		X
Is there a significant possibility that the project will cause participants to become distressed or harmed in ways that may not be apparent to the researcher(s)?		X
Will the project incur risks of breaching participant confidentiality and anonymity that arise specifically from the use of electronic media?		X

If you answered **Yes** to **any** of these questions:

- Explain why you propose to use electronic media.
- Explain how you propose to address the risks associated with online/internet research.
- Ensure that your answers to the previous sections address any issues related to online research.

14 Other ethical risks

Question	**Yes**	**No**
Are there any other ethical issues or risks of harm raised by your project that have not been covered by previous questions?		X

If you answered **Yes** to **this** question:

- Explain the nature of these ethical issues and risks.
- Explain why you need to incur these ethical issues and risks.
- Explain how you propose to deal with these ethical issues and risks.

15 Research with non-human vertebrates[3]

Questions	**Yes**	**No**
Will any part of your project involve the study of animals in their natural habitat?		X
Will your project involve the recording of behaviour of animals in a non-natural setting that is outside the control of the researcher?		X
Will your field work involve any direct intervention other than recording the behaviour of the animals available for observation?		X
Is the species you plan to research endangered, locally rare or part of a		X

[3] The Animals Scientific Procedures Act (1986) was amended in 1993. As a result the common octopus (*Octopus vulgaris*), as an invertebrate species, is now covered by the act.

sensitive ecosystem protected by legislation?		
Is there any significant possibility that the welfare of the target species or those sharing the local environment/habitat will be detrimentally affected?		X
Is there any significant possibility that the habitat of the animals will be damaged by the project such that their health and survival will be endangered?		X
Will project work involve intervention work in a non-natural setting in relation to invertebrate species other than *Octopus vulgaris*?		X

If you answered **Yes** to **any** of these questions:

- Explain the reasons for conducting the project in the way you propose and the academic benefits that will flow from it.
- Explain the nature of the risks to the animals and their habitat.
- Explain how you propose to assess, manage and mitigate these risks.

16 Blood Sampling / Human Tissue Analysis

Questions	**Yes**	**No**
Does your project involve blood sampling or human tissue analysis?		X
If your study involves blood samples or body fluids (e.g. urine, saliva) have you clearly stated in your application that appropriate guidelines are to be followed (e.g. The British Association of Sport and Exercise Science Physiological Testing Guidelines (2007) or equivalent) and that they are in line with the level of risk?		
If your study involves human tissue other than blood and saliva have you clearly stated in your application that appropriate guidelines are to be followed? (e.g. The Human Tissues Act, or equivalent) and that they are in line with the level of risk?		

If you answered **No** to **any** of these questions, please provide more information:

Note: This checklist is based on an ethics approval form produce by Research Office of the College of Business, Law and Social Sciences at Nottingham Trent University. Copyright is acknowledged.