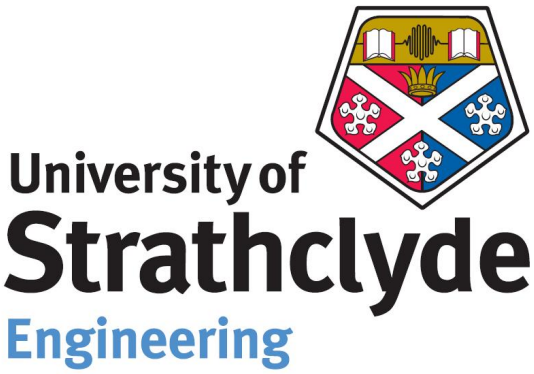

A qualitative analysis of students' naturalistic learning processes during their first experience in problem-based learning.

A thesis submitted to

University of Strathclyde

in 2019

for the degree of Doctor of Philosophy

by Seren Mabley

Department of Chemical Engineering

School of Psychological Sciences and Health

Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

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As per the regulations for submission according to the University of Strathclyde, I can confirm that I am the first author of all the above papers, responsible for all aspects of data collection, analyses and reporting of the research.

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Abstract

Future global challenges that engineering graduates face have placed demands on engineering education and how graduates develop professional skills while studying at university. Such demand has seen an increase in the use of pedagogies like problem-based learning (PBL) that provide opportunities for developing professional skills such as teamwork and problem-solving.

The current research in PBL is mainly focused on evaluating the pedagogy on a curricula scale rather than the collaborative processes involved in such a student-centred and active pedagogy.

This thesis is aiming to address this and gain an insight and understanding of students' naturalistic learning processes during their very first experience with problem-based learning (PBL); to identify strategies which are used by team members to manage the PBL process.

This has been successfully investigated through analysis of naturalistic observations of students in PBL sessions. The thesis reports the analysis of 80 hours of naturalistic video data collected from students, studying at the University of Strathclyde, during their PBL sessions. This data was then analysed using qualitative content analysis, a method that enabled the author to identify and describe strategies observed in the video data using a systematic and scientific approach.

The strategies identified indicate that the students are not conducting PBL sessions as they are designed or intended to be held, particularly when the teams are managing their own group processes. The findings of this study emphasize just how complicated it can be to transition from a passive learning role (e.g. during lectures) to an active role (e.g. in PBL),

where the responsibility of learning is with the students themselves.

The study highlights how video recording data can be used to provide a novel contribution to the research on problem-based learning in engineering education and broaden the understanding of strategies used by students to manage the problem-based learning process.

1 Introduction

This chapter introduces this thesis and explains the motivation behind the study. It reviews the context of the project and the aims which were set out to be addressed. An overview of the entire thesis structure is included at the end of this chapter.

As the world faces rapidly evolving global challenges, particularly considering the increasing population and depletion of resources, engineering professionals face the task of providing solutions to these challenges to ensure social and economic growth in a sustainable manner (Davidson et al., 2010; Royal Academy Of Engineering, 2019). However, there is a concern that modern engineering graduates are beginning professional work without the necessary preparation; current educational practices are so far removed from the reality of industrial work that graduates have difficulty adapting (Chan & Fong, 2018).

In the 2017 global university employability ranking problem-solving and collaboration were identified by over 80% of respondents (industrial professionals) as two of the key qualities graduates need (Baker, 2017). This is not surprising perhaps since graduates are required to face the ever-changing demands of current workplaces. Unfortunately, these skills seem to be underdeveloped for applicants and a similar skill gap is seen within the current engineering workforce (Connor et al., 2000; The institution of Engineering and Technology, 2017; Randstad UK, 2019; Spinks et al., 2006).

Educational and industrial professionals have different opinions on what is important for working life, with academics focusing mainly on technical knowledge and often overlooking the need to develop students' professional skills (Warnock & Mohammadi-Aragh, 2016). There are currently few opportunities, within undergraduate

chemical engineering curricula, for students to improve their professional skills which are necessary to help solve the global challenges facing the engineering industry in the twenty-first century (Fitzpatrick, 2017).

Grant & Dickson (2006) discuss a survey administered by the World Chemical Engineering Council (WCEC, 2004) which demonstrates how students capabilities are quite different to industry requirements. This survey was taken by young graduates of chemical engineering during their first five years working in industry. The results show that the top required competency was problem-solving, a competency which was not perceived to be possessed by students when they had graduated. This misalignment means the students are leaving education to work in industry without the preparation they feel necessary once they have gained more experience.

It is important for engineers to gain the ability to work collaboratively to solve problems and deliver viable solutions to these local and global challenges. This need has instigated important changes in the engineering education curriculum over recent years and in particular, in the skills that are required of an engineering graduate to operate in such fast-paced environments.

Further to this a study investigating students' beliefs about problem-solving found that students make a distinction between classroom and workplace problems, with the belief that classroom problems are simplified well-structured exercises, not on par with the ill-structured realistic cases seen in the workplace (McNeill et al., 2016). This suggests that students do have some understanding that a higher level of skill is required by employers but are yet to achieve it.

Reported in literature it is seen that undergraduate students rely heavily on the use of sample solutions and struggle to establish answers for tutorials independently (Warnock & Mohammadi-Aragh, 2016; Woods et al., 1997). This is an issue related to learner autonomy; it demonstrates that students are lacking the self-regulation necessary to become an expert in problem-solving (Perels et al., 2005). This gives further evidence to show that students choose to use a 'surface' (learning by rote/retention) based learning style to memorise material rather than having a clear grasp of fundamental underlying

principles that permits generalisation to novel problems (Mayer, 1998; McParland et al., 2004; Wood, 2004). This can be explained primarily as the result of the didactic traditional teaching approach; the main instructional method being lectures with little interaction between students, their peers and the tutor.

An investigation by Bassok (1990) found that even when the development of problem-solving skills is promoted within learning it can still be difficult to transfer the learnt knowledge to new contexts. Students fail to abstract similarities between the learnt (when knowledge was acquired) and transfer (when knowledge is applied) situations without being prompted to do so (Bassok, 1990). This suggests that even when undergraduate students possess the knowledge and skills needed to solve a problem, they have learnt in a way which makes it extremely challenging to practise them in different situations and apply them to new problems or contexts.

It has been recognised that traditional lecture-based teaching methods do not promote the development of professional skills, such as problem-solving and teamwork, and consequently, higher education institutions must use active learning methods in their curriculum (Lamb et al., 2010; Smith et al., 2005). The use of collaborative, authentic and student-centred pedagogies, such as problem-based and project-based learning can help to develop professional skills (Michael, 2006; Lamb et al., 2010).

Problem-based learning (PBL) has been implemented within higher education (e.g within medicine, engineering, law and psychology). It is used as a method that can help to promote the development of skills, such as communication, problem-solving and teamwork, which are desired by employers and not yet adequately developed by graduates. It is an authentic pedagogy which uses ill-structured problems which are situated in a realistic context and gives students responsibility for their learning processes (Davidson & Major, 2014; Duch et al., 2001; Vos & de Graaff, 2004).

PBL is an approach which has not yet been widely implemented within engineering education specifically in a UK context. The majority of research conducted so far concerns the effectiveness or impact that PBL can have on undergraduates learning (Hak & Maguire, 2000; Svinicki, 2007). The early reviews would view PBL as a black box and evaluate

its effectiveness by measuring the performance of students after a module undertaking problem-based learning. In more recent years there has been a shift towards looking to understand PBL through a qualitative lens and examine group processes in more detail (Hammar Chiriac, 2008; Imafuku & Bridges, 2016). However, there is still much to learn about the processes which occur within these problem-based learning sessions to gain addan understanding of how the PBL teams manage this new pedagogy.

This thesis is aiming to explore what happens in practice during PBL sessions and 'how' it works to help learners develop the skills they need to succeed in industry. The thesis reports on a corpus of video-recorded data of students working within problem-based learning sessions for the first time. The particular aims and research questions intended to be addressed are seen below. The research questions which informed the literature review and research design are presented here:

- What strategies do students use in different phases of PBL to aid their collaborative problem-solving process?
- How do learners manage the PBL process during their first experience with a PBL pedagogy?

Therefore, this study uses naturalistic observations to analyse students' learning processes during their first experience with a problem-based learning pedagogy. These questions were also the driving force to the data analysis process, which is further explained in chapter 3. The final section of this chapter presents a full overview to indicate the chapters in this thesis and their contents.

This thesis has been organised into nine chapters, a brief description of each of these has been included below.

The introduction (chapter 1) presents the context and motivation behind the thesis. This chapter outlines the research questions that led to the decisions which have guided the project. This is followed by the literature review (chapter 2) provides a wider background to this project. It considers the development of learning theory and the effect this has on instructional environments. Problem-based learning is reviewed in detail consisting of PBL history, defining features, models and research within the PBL field. Problem-based

learning is the learning environment from which the data was collected for this thesis and therefore a significant section is dedicated to this.

The research design is explained in chapter 3 and the reasoning for these decisions are discussed. It reports on the theoretical framework, the methodology and analysis method in addition to describing the data corpus collected for this thesis.

The results and analysis were divided into three distinct chapters. Chapter 4, the brainstorming phase of PBL, presents the first analyses where the initial phase of PBL was studied. This outlines the coding frame developed from the data corpus and examples of the strategies identified.

Chapter 5, the reporting phase of PBL: round 1, is the second analysis chapter. It presents the findings which were based on the study of the reporting phase of PBL during the first round of data collection. This follows the same structure as chapter 4.

Finally, chapter 6, the reporting phase of PBL: round 2, presents the final analyses in this thesis. It includes examples of the findings from studying the reporting phase of PBL during the second round of data collection.

The results and analytical chapters are followed by a discussion (chapter 7), which gives a detailed consideration of the findings in this thesis, including summaries of the three analysis chapters. Alongside a comparative analysis between these different contexts to discuss the effect this has on students behaviour.

Overall conclusions from the thesis with recommendations for future research which can lead on from this project are presented in chapter 8.

2 Literature Review

This chapter is focused on exploring the background, theoretical framework and context of the research, by presenting a review of the relevant literature and current research. The chapter begins by discussing how learning theory has developed and the influence this development can have on instructional environments and teaching methods. Then, a comprehensive discussion on problem-based learning is provided including the current research being conducted in this field with an emphasis on studies with similar context to this thesis.

2.1 Learning Theories

This section will discuss the development of the theories which describe the learning process to later detail how these influence teaching and instructional pedagogies. There are several theories to explain how people learn, it is a subject that has been widely debated in the literature. Bransford et al. (2000) provide a comprehensive review of these theories and the discussions which surround them. The three main theoretical approaches to learning are; behaviourism, cognitivism and constructivism. These are the concepts which will be examined in this section.

The first ideas of how to describe learning were based purely on changes in behaviour, that learning occurred only through some representation of a stimulus being associated with a response action or behaviour. John B. Watson was the first to name this as behaviourism. In his classic text (1913) he stated that psychology would only be a true science if it investigated only observable and measurable phenomena (like other physical sciences). This led to the concept that learning was best understood in terms of changing

behaviours with no consideration of the mental activity involved (Pritchard, 2013; Schunk, 2012).

Edward L. Thorndike also developed a similar theory of learning at the beginning of the twentieth century which he named connectionism. The majority of his work was documented in the series 'Educational Psychology' (see 1913a; 1913b; 1914). Similarly to behaviourism, he believed learning involved relating sensory experiences to neural impulses; a stimulus−response association. He believed that learning would often occur through a trial and error technique, and could be further confirmed by repetition.

Behaviourists then began to investigate how environmental factors could have an impact on this stimulus−response association. Ivan Pavlov (1927) is most famously known for his work on classical conditioning. His work demonstrated how animals (and humans) could be conditioned to produce a specific response to a specific stimulus. Operant conditioning was later developed by Burrhus F. Skinner (1938) whose work established that the introduction of positive and negative reinforcement could also influence the production of a specific response to a conditioned stimulus.

Behaviourism placed all emphasis on how the learning process is manifested through a change in behaviour and how environmental factors can influence this process. There was little focus on how the learner can influence the acquisition of knowledge, presenting the learner as reactive to external stimuli with no active role in discovery (Ertmer & Newby, 2013). This theoretical framework supports the idea that continual reinforcement with feedback can be used to alter behaviour to induce the correct response. This suggests that it is necessary for learners to practice actions and be given feedback on them to further solidify their knowledge. Although there are many aspects of these theories which were correct and continue to be, they do not fully cover the concept of learning because they ignore the active sense-making thinking processes which the learner engages in during many situations. Subsequently, other theories were developed to account for these.

The cognitivist approach arose when theorists acknowledged the role of the mental processing which takes place during learning. Figure 2.1 is a simple diagram that has been adapted from Atkinson & Shiffrin (1968, 1971) who created the cognitive model of

information processing within memory. This diagram shows that in contrast to the belief that a stimulus automatically triggers some response to the environment there is active processing of the input through processes such as rehearsal. Cognitivism believes that following a stimulus some information will reach working memory where it is processed and is taken up by long term memory or discarded, this process is called encoding. The reverse process is called retrieval and relates to when long term memory provides information connected or analogous to the original stimulus resulting in further learning and external response to the environmental input. This is only the basic procedure but it is integral to how cognitivism defines learning.

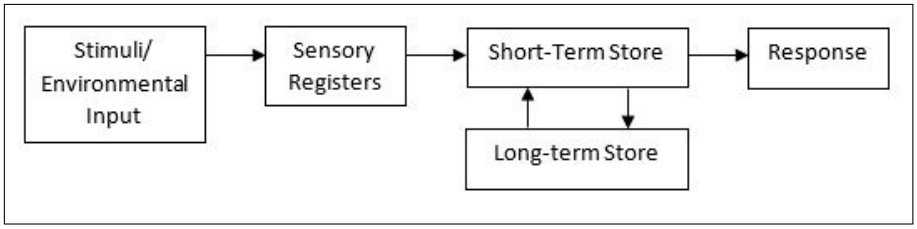


Figure 2.1: Schematic adapted from Atkinson & Shiffrin (1971) to show the basic cognitive process of learning.

Although there are nuances between different theories fig. 2.1 provides the overriding structure of mental processing in memory and learning as we know it today. It is the basis for information processing theory, one branch of cognitivism that focuses on the internal processing that occurs as an intervention between an input and a response (Schunk, 2012). There are two major implications of this concept on instruction and they are related to how information is structured and presented to students; an instructor can aid learning through creating meaningfulness. This is achieved by staging the content in a way that is recognisable i.e. it is likely to result in connections to their long-term memory and thus more likely to be taken up and remembered.

In the information processing theory, the learners' working memory can only process a few ideas at one given time which is called cognitive load. If this limit is reached or surpassed during instruction this could hinder learning because it is not possible for all the knowledge to be processed and remembered. Austin (2009) demonstrated this through an experiment that considered display design in improving the performance of students in transfer tests. The study found that while having both narration and animation

improved performance providing students with narration, animation and text hindered performance suggesting that working memory was overloaded. This sentiment has also been reported by Mayer (1999) who suggests that transfer is hindered when either visual or verbal working memory is overloaded. Mayer was also investigating the optimal design of multi-media resources.

Social cognitive theory (SCT), another branch of cognitivism, was pioneered by Albert Bandura (1986). This theory is based on the notion that social settings can greatly influence learning. SCT says that learning occurs through both doing and through observing, extending the idea of information processing to show that students can learn experientially. This theory also makes a distinction between learning and performance of a previously learned behaviour, a concept demonstrated previously in experimental work by Tolman & Honzik (1930) when arguing against the notion that reinforcement is necessary for learning.

One of the more abstract beliefs that SCT incorporates is one called triadic reciprocality, this is the idea that there are three causal factors which work mutually to determine an outcome. A diagram has been created, based on a similar figure from Bandura (1986) (as printed in Schunk, 2012), to depict this concept and can be seen in fig. 2.2. This figure shows how behaviour, cognition and environmental factors can all interact with one another to influence psychological processing (Bandura, 1978). It is clearly stated however that although the diagram shows how interaction can be in any direction this does not mean to insinuate that factors have equal influence, at certain times one can be more prominent than another (Bandura, 1985).

Figure 2.2: Schematic diagram to represent the concept of triadic reciprocality, adapted from figure in Bandura (1986) (as printed in Schunk, 2012)

The social cognitive theory also assumes individual learners exercise control and influence over their own decisions regarding events that affect their lives (Bandura, 1997). This idea is centred around the concept of self-efficacy, the belief one holds about their ability to succeed in a specific task and how this can alter an individual's behaviour. This shows

how learning is affected by the belief that an individual holds on their capability to succeed in a specific task and that each individual has their agency. Figure 2.3 shows a diagram to visualise how efficacy beliefs are linked to outcome expectancies. Perceived self-efficacy is a judgement of a person's ability to perform and outcomes expectancy is the visualised consequence of this performance. The concept claims that a perceived self-efficacy can lead to a visualised outcome and either encourage or discourage the individual to engage with the task.

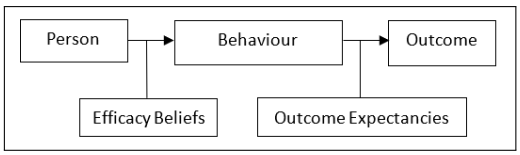


Figure 2.3: Schematic diagram to represent the concept of self-efficacy and its effect on outcomes adapted from figure in Bandura (1997)

SCT can inform instructional methods through the use of modelling; by demonstrating a process for observational learning (Bandura, 1969). This can help to increase students' self-efficacy. Another important quality to motivate learners to further their knowledge. An example of this is the use of a worked example, the model, to explain how a problem can be solved.

Looking generally at cognitivism neither of these theories can completely explain the process of learning, information processing theory ignores the environmental factors that can determine knowledge acquisition whereas SCT gives little insight into the role of memory in learning. These are both key concepts that must be combined to get a real grasp on how people learn. This then led to the emergence of constructivism the most recent theory of learning which is discussed below.

Constructivism is the newest understanding of learning, described as epistemology or a physiological explanation of learning rather than a theory (Schunk, 2012). It is a concept which disregards some of the underlying assumptions behind cognitivism including the idea that learning occurs similarly for all people and that situations or interactions cannot affect a person's thinking (Greeno, 1989). Constructivists believe that each learner's knowledge is unique and is built up from their own individualised experience in all situations (Cobb & Bowers, 1999). Knowledge cannot be detached from the context in which it is acquired (Bredo, 2006; Ertmer & Newby, 2013). This is contradictory to the supposedly objective nature of knowledge as seen in behaviourism and cognitivism where

it is assumed to be true and is merely provided by an external party. Constructivism claims that memory is not 'what the learner sees' but it is 'what the learner thinks they see', i.e. an internal representation or interpretation of the stimulus they were presented with (Svinicki, 2010).

There are two branches under the constructivism domain; cognitive and social constructivism. Cognitive constructivism was developed by Jean Piaget (1952; 1959) and follows the principle that knowledge is constructed cognitively by persons themselves with some external influences (Schunk, 2012). The main adaptations were that the learning process was seen to be dependent on a student's developmental stage which correlates biological age and that children cannot push beyond their cognitive-developmental stage i.e. students cannot learn what is deemed to be above their abilities (Pritchard, 2013). Piaget also emphasises the need for learners to discover knowledge and gain understanding autonomously, rather than being shown how to do something.

Social constructivism originates from Lev Vygotsky's sociocultural theory (1962; 1978). This is another branch of constructivism which focuses on the concept that learning is largely influenced by the social environment. In this case, learning occurs as an internalisation of social experience and therefore it is promoted by collaboration with others including parents, teachers and peers. A specific case would be those acting as teachers helping to 'scaffold' an individuals development. The region between a learner's current capability and the stage they can comfortably achieve given their current developmental level is called the zone of proximal development and is not related to their biological age. There are no assumed limitations regarding cognitive levels of capability in social constructivism; Vygotsky believes that given enough encouragement learners can surpass any boundaries.

A more recent review by Lourenço (2012) documents existing comparisons between Piaget and Vygotsky's view on constructivism. This paper notes that the early discussions state the major difference that Vygotsky believed knowledge construction to occur through interactions with others whereas Piaget believed it to be a largely solitary and internal activity. Lourenço argues this is an oversimplified interpretation of these theories as he explains they both adopt a relational perspective. This misunderstanding led to

another phase of comparison where the two theories were pinned as similar since they share a number of key characteristics (Bidell, 2010; Glassman, 1995). Marti (1996, pg. 58, emphasis added) lists these principles as the *"genetic perspective, dialectic approach, anti-reductionism, anti-dualism, importance of action, primacy of processes* and *qualitative changes*".

Lourenço (2012) claims there is one true fundamental difference between Piaget and Vygotsky. That Piaget believed knowledge construction to be an autonomous and spontaneous process when an individual confronts the social and physical world. Whereas in contrast, Vygotsky believes that learning occurs heteronomously as a consequence of social interactions and experiences. Vygotsky attaches importance on the 'more knowledgeable other' and expresses a need for collaboration. The author of this thesis believes in a social constructivist view of learning where knowledge is individualised, subjective and it is also influenced by a person's particular experiences. Knowledge is constructed and re-constructed based on how an individual connects new information and environments to previous experiences. Learning is dependent on observations of and interactions with the social environment, thus it is heavily reliant on collaboration with peers. Barkley et al. (2014) also emphasise the importance of collaborative group learning because knowledge is co-constructed through interactions between two or more people. For example, when a group reach consensus and create shared understanding.

Situated cognition is a theory leading from constructivism which expands on the notion that learning is dependent on interactions between a person and their situation; that cognitive processes are not only happening in the mind (Robbins et al., 2009; Suchman, 1987). The work of Lave (1988) (as cited by Greeno, 1989) observed how participants when solving arithmetic problems would unknowingly change their technique relative to the situation. One example from Lave (1988) shows how when measuring three-quarters of two-thirds of a cup of cottage cheese the solution was not calculated arithmetically but demonstrated practically. The participant measured out two-thirds of a cup then spread this out in a circle and divided into quarters to discard one. This shows how the situation can impact the method used during problem-solving.

Situated cognition has several parallels with social constructivism but it is more related to

instructional environments. The main message is that cognitive processes are anchored in activities and their context as well as the culture in which they were first learnt (Brown et al., 1989). Schunk (2012) explained this concept particularly well, saying that if a student is taught a topic using one particular instruction e.g. through lecturing then the learning will become set in this context and could hinder knowledge acquisition and application when exposed to new contexts or teaching techniques. This just proves how important it is to make sure that the learning context is related to the desired outcomes as well as where the knowledge might be applied.

A similar concept has been further discussed by Biggs (2014) called constructive alignment; where the instruction, objectives and assessment of learning must all be focused on the same results so that it is not hindered by its context. This is another argument for instruction to be designed to a realistic and relevant context to close the gap between when learning occurs and when it might need to be applied. This is to encourage and ensure transferability and life-long learning for students who are applying this knowledge in the future.

2.2 Instructional Implications

A social constructivist view of learning leans towards active and authentic pedagogies which require students to interact and collaborate with their environment and peers. The traditional 'lecture-based' pedagogical approaches follow a more behaviourist/cognitivist view of learning where the learner is assumed to be an *"empty vessel waiting to be filled up*" (Perrenet et al., 2000, pg. 346). This positions the learner in a passive role being told information to be memorised. In contrast, social constructivism values the active process of discovery since each persons' knowledge is unique and subjective to their own experiences. The social constructivist view of learning also proposes that instructional techniques which provide the opportunity for collaboration can significantly affect knowledge construction.

Discovery learning is one of the pedagogies that encompasses the principles of social constructivism. It is a method where students are given little to no guidance when given problems or asked questions. Learners must discover the content for themselves (Bruner,

1961). As this technique was initially proposed it was suggested that teachers would provide the problems and questions then provide feedback on solutions but would not be involved or give guidance during the learning or discovery process.

Discovery learning has been criticised because instructors believe that by leaving the students to obtain the knowledge themselves it would take a much longer time to cover the same amount of material using lectures or other instructive methods (Prince & Felder, 2006). Because of this concern some instructors use a method called guided discovery. A combination of inductive discovery learning with the traditional didactic approach. Here the overall curriculum and its learning objectives are introduced through lectures but the deep learning occurs through self-directed discovery (Spencer & Jordan, 1999).

Inquiry teaching and learning is similar to discovery learning but the instructor is more prominent and can give more direction to learners. It is a process where students are given a problem and questions are posed from the instructor repeatedly to create a constructive and insightful dialogue (Schunk, 2012). There is a further classification that differentiates inquiry learning into structured, guided and open. Staver & Bay (1987) state that structured inquiry is where students are presented with a problem without knowing the results but both procedures and materials are given; guided inquiry is when students are given a problem but must design the method to solve it and open inquiry is when a learner has to formulate the problem as well as its solution.

One concern with inquiry teaching is that it is focused on one-to-one tutoring, so there is little opportunity for collaboration with peers. Inquiry teaching also requires instructors to undertake extensive training to make sure that questions posed are challenging but not impossible. They must target the zone of proximal development as explained by Vygotsky.

One other instructional method that contrasts the traditional individualistic and competitive cultures present in education was the concept of cooperative learning. This was developed by Johnson et al. (1991, 2014). It is not only the use of group teaching but has specific characteristics to make it truly collaborative learning. These principles are listed below (as seen in Johnson et al., 1991, pg. 6):

- Positive Interdependence
- Face-to-face Promotive Interactions
- Individual Accountability
- Social Skills
- Group Processing

These principles are required to ensure that teams are not just working on individual tasks at the same time but are also actively working together to reach a shared goal. These features are not only distinctive to cooperative learning but could be put in practice when implementing any pedagogy that uses small group teaching.

Situated learning is an instructional method informed by situated cognition theory. The basis of this is the use of the cognitive apprenticeship (Hennessy, 1993). This is a technique where learners observe and are coached by experts to acquire subject domain knowledge and develop professional skills, such as problem-solving. Collins et al. (1987) explains this concept as a repeated process of the expert demonstrating a task which the learner (apprentice) observes before attempting to execute this same task with some guidance and input from the expert. This process is synonymous with the ideas of modelling (demonstration) and scaffolding (providing guidance) within classroom instruction.

The purpose of cognitive apprenticeship and situated learning is to give learners practice in the professional environment. This was clearly stated by John S. Brown when he said:

> *Apprenticeship helps to emphasize the centrality of activity in learning and knowledge and highlights the inherently context-dependent, situated, and en-culturating nature of learning (Brown et al., 1989, pg. 39).*

This closely fits with the theoretical framework of situated cognition which emphasises the need for students to learn in an authentic and realistic context. This feature is an incredibly important aspect of constructivist pedagogies that can help to aid knowledge transfer and life-long learning.

Project-based learning is a pedagogy which has a similar approach since it also involves contextualising learning by asking students to complete complex tasks based on realistic and authentic situations (Blumenfeld et al., 1991). It is a student-centred method that puts the onus on the learner to organise and conduct their learning based around a large group project; a pedagogy very similar to problem-based learning. The main context of this thesis is problem-based learning so this is more broadly described and reviewed in section 2.3.

The pedagogies which have been discussed in this section are all informed by situated cognition and based on a social constructivist world view. These instructional methods have received some criticism from many researchers and academics who continue to reject this theoretical epistemology. In particular, the paper by Kirschner et al. (2006) gives explanation to why they believe “minimally guided instruction" is not effective for learning. The main argument is that there are no controlled studies to support the implementation of minimally guided constructivist instructional methods. Kirschner et al. (2006, pg. 84) continue to state that the constructivist epistemology has led to *“the rejection of instruction based on the facts, laws, principles, and theories”* claiming that these will not be truly learnt if being taught in a practical experiential setting without direct instruction. This same concern has also been reported by Osborne (2015) when discussing critiques of constructivism and constructivist pedagogies.

Hmelo-Silver et al. (2007) wrote a response to Kirschner et al. (2006), in this response the main message is that despite PBL being a student-centred pedagogy it should not be considered minimally guided. They state that extensive scaffolding in place to ensure that knowledge in the intended subject domain is covered. In their book chapter on student learning, Anderson & Johnston (2016, pg. 73) explain that critiques on constructivism such as those from Kirschner et al. are *“made of extreme case or straw man formulations of the constructivist idea”*. The constructivist framework is compatible with fact learning, it does consider scaffolding but it does not negate the influence of the environment on learning processes.

The final constructivist pedagogy which will be discussed in this literature review is that named problem-based learning (PBL). Since this was the context for the data studied in

this thesis a more detailed review for the PBL pedagogy was necessary. This is seen in section 2.3 here the history and models of PBL are explained and this leads into a review of the current research investigating PBL.

2.3 Problem-Based Learning (PBL)

This section gives an introduction to the constructivist pedagogy problem-based learning (PBL) and its history before leading into a more detailed description of its use in instruction. In addition, this section includes a review of the research currently taking place in the field of problem-based learning and more specifically within the engineering educational context.

2.3.1 PBL: A History

PBL was first introduced in the 1960s in medical education. The pedagogical approach was implemented at McMaster University Canada led by Howard S. Barrows. (1980). In the context of medical education, PBL meant working to address patient problems by incorporating knowledge from a variety of disciplines. This way students were not only learning the content but they were able to apply it in practice from the very start (Barrows & Tamblyn, 1980).

The development of the PBL curriculum and its success at McMaster led to more medical schools adopting a problem-based approach in their curriculum (Barrows, 1996; de Graaff & Kolmos, 2007). The medical schools in Maastricht (the Netherlands) and Newcastle (Australia) were the first to develop their problem-based learning curricula in the early 1970s. PBL has since been introduced to a huge number of medical schools among other health sciences course programs. Following this, in the 1980s a PBL curriculum spread into several other subject departments including, engineering, education, law, and business (de Graaff & Kolmos, 2007).

The first implementation of problem-based learning in an engineering context was also in Canada at McMaster University; a problem-based learning pedagogy was implemented into the chemical engineering program by Woods (1996); Woods et al. (1996). This PBL

program in the chemical engineering department at McMaster was originally implemented in the early 1980s. It was the result of a change in direction where the department wanted to focus its curriculum more on students' lifelong learning and providing the opportunity to develop skills necessary in the future.

After implementing the problem-based learning pedagogy at McMaster, Woods et al. (1997) created a problem-solving program to be completed alongside the core chemical engineering curriculum. The problem-solving program introduced four modules which were explicitly concentrated on coaching and practice in problem-solving skills. This was due to an observation that students were struggling to transfer their knowledge when being asked to tackle unfamiliar problems.

PBL is now widely used as the main pedagogy at many institutions globally, including McMaster (Canada), Newcastle, Queensland and Sydney (Australia), Maastricht and Twente (Netherlands), Roskilde and Aalborg (Denmark), Bremen (Germany) and Linköping and Chalmers (Sweden) (Graham, 2012; Kolmos et al., 2009). There are also examples where PBL is used as a partial strategy when it is combined with a conventional curriculum (Cawley, 1998).

Similarly to the pedagogies discussed in section 2.2 PBL has received critique, specifically within the engineering education context. In their review, Perrenet et al. (2000) assess the suitability of PBL for engineering education. They suggest that it might be problematic to teach using purely PBL since engineering knowledge is hierarchical and if pre-requisite fundamentals are not properly covered this can cause issues for future learning. This gives incentive for thorough consideration to be taken when implementing a PBL curriculum to ensure that the right guidance is provided so this issue can be avoided.

2.3.2 Defining Features

As a pedagogy problem-based learning is grounded in and informed by the social constructivist world view and situated cognition theory. It is a pedagogy that situates learning in a meaningful context, it offers an opportunity for collaboration and practical experience during learning. The importance of experiential learning was first emphasised in the traditional works of Dewey (1938) and Kilpatrick (1918, 1921) (as cited in

Hmelo-Silver, 2004, pg. 236).

The key characteristics of problem-based learning are listed and described below. These principles are the foundations of problem-based learning and they link the social constructivist theory (as discussed in section 2.1) to real instructional practice. They are the defining criteria for a problem-based learning pedagogy that are met by all different types of approach. A thorough description of the different models of problem-based learning and how the learning process occurs is included later in section 2.3.3.

- Student-centred learning (Davidson & Major, 2014; de Graaff & Kolmos, 2003; Hung et al., 2007). This means that the students are required to take responsibility for their learning; they are active participants in the process. This is an inherent aspect of problem-based learning since the theory states that knowledge is constructed and reconstructed individually, it is not a passive process.

- Problem-focused (Davidson & Major, 2014; Dolmans et al., 2005; Hillman, 2003; Hung et al., 2007). The learning process is focused on ill-structured and unfamiliar problems. These are used as scenarios which need to be researched and solved by the students. This feature reflects the situated nature of PBL and ensures that the learning takes place in a context similar to where it will be applied.

- Real-life situations (Dahlgren, 2000; Davidson & Major, 2014; de Graaff & Kolmos, 2003; Hmelo-Silver, 2004). The problems are based on authentic real-life situations which closely relate to professional work. The aim of this is to aid students transfer of knowledge and skills in future situations. This even further emphasises how PBL is based on situated cognition by providing problem cases which relate to those met in the workplace.

- Self-directed learning (Dahlgren, 2000; Davidson & Major, 2014; Hung et al., 2007). The students are expected to formulate learning objectives, conduct independent research and identify resources to address their developed learning objectives. This is according to the characteristics of self-directed learning as defined by Zimmerman (1990). This reiterates the position of a learner as an active participant in knowledge construction while also offering the opportunity to exercise their metacognitive

skills.

- Collective group work (Dahlgren, 2000; Davidson & Major, 2014; de Graaff & Kolmos, 2003; Dolmans et al., 2005). A major principle of PBL is the use of collaboration. PBL sessions are conducted as part of a small group (between 5-7 persons) of students to promote interactions between peers. The use of collective group work is based on the social constructivism theory which believes that learning is enhanced by peer-to-peer interaction.

- Tutor as facilitator (Dolmans et al., 2005; Hillman, 2003; Hung et al., 2007). Since PBL is student-centred and self-directed tutors are no longer the experts there to provide correct answers. Tutors work as coaches to facilitate the learning process and guide students in the intended direction without direct instruction.

This section has outlined the key characteristics and principles which underpin the problem-based learning pedagogy. This also shows how these features are connected to the theory behind the development of this instructional method. The following section elaborates on the types of PBL that are currently known and how they are different.

2.3.3 PBL Models

As an instructional method PBL can be implemented in a variety of ways, yielding different instructional models guided by the purpose of learning. There are modes of PBL as implemented in curricula, the wider setting within a whole degree programme. There are also models of PBL as implemented in the classroom, these identify the detailed stages and phases in PBL.

In Curricula

There are a number of curricula modes which are implemented in PBL. These have been categorised by Savin-Baden & Major (2004) are described below.

Mode 1 Single module approach: PBL is implemented in one module of a course programme.

Mode 2 Problem-based learning on a shoestring: PBL is implemented by interested

academics in different modules but this rarely transcends disciplinary boundaries.

Mode 3 The funnel approach: PBL is implemented in the final year following the first year which is lecture-based and second year which incorporates problem-solving.

Mode 4 The foundational approach: PBL is only implemented once the students have gained knowledge of the fundamentals through a more traditional lecture-based approach.

Mode 5 The two-strand approach: PBL is implemented in combination with other mixed methods approaches across all years of a degree programme.

Mode 6 Patchwork problem-based learning: PBL is implemented in the whole curriculum but different modules follow differing time frames. There is no integration between disciplines.

Mode 7 The integrated approach: Here PBL is part of the curriculum philosophy, all problems are linked to one another.

Mode 8 The complexity model: PBL is implemented as an approach to curriculum design which transcends subject boundaries and embraces knowledge.

These show the modes of PBL as seen within a wider setting for a whole degree programme. How PBL is implemented in curricula can have a large effect on its impact on the students learning. Modes such as 6, 7 and 8 offer a more global approach where the students will learn primarily through problem-based learning. Contrastingly modes 1 and 2 comprise of isolated instances where PBL is implemented by academics who are interested and passionate about this pedagogical approach. Modes 3, 4 and 5 comprise of PBL combined with other pedagogies either simultaneously or in a linear way.

Social constructivism is the theory which has led to the development of the PBL pedagogy and is constantly used to inform instructional practice as it states that knowledge is a constructive and unique process. Despite this, there are still many curricula which use a combination of teaching approaches (modes 1-5 from Savin-Baden & Major (2004)) meaning the students must adapt and move between an active and passive learning role (during lectures or demonstrations). This could have an impact on the effectiveness of

problem-based learning as a technique to improve learning.

The data reported on in this thesis has been collected through video recording students PBL sessions. The curricula mode in this instance follows mode 1, the single module. The module studied is the only instance where the students work using a PBL pedagogy. Here the curricula modes have been described since there will be a disparity between students behaviour and strategies when they have been exposed to a PBL pedagogy throughout their degree programme versus those students who are new to the PBL instructional method.

In the Classroom

This section is focused on the different types of PBL that can be implemented in the classroom. Here the intricate details of how PBL can be used in practice.

Most models in the classroom setting centre around the use of a problem scenario as the starting point for learning, as explained in section 2.3.2. However project-based learning (PjBL) uses more complex and broader projects based around a meaningful question (de Graaff & Kolmos, 2003). Boud (1985) argues that both PBL and PjBL are the same, whereas Savin-Baden (2007) specifies them as unique and distinct types of problem-oriented pedagogy. One major reason for these pedagogies to remain distinct is because PBL is oriented towards knowledge acquisition and PjBL is focused on knowledge application (Perrenet et al., 2000).

The main differences between PjBL and PBL are the recognised objectives (Savin-Baden, 2007). In PjBL the aim of the pedagogy is for students to produce a particular outcome and solution to the given question; often documented through the means of a collaborative project report or presentation. PBL is much less focused on a specific outcome, its primary aim being focused on problem management and group processes. There is also a major difference in terms of timing, PjBL is composed of one major project to be completed throughout an entire semester whereas PBL comprises of several problem scenarios each one completed through the course of one week (a much shorter time-frame).

Perhaps the most famous model of PjBL is the Aalborg Model (Kolmos et al., 2006).

Figure 2.4 shows a visualisation of the processes which are involved in the Aalborg model of PjBL. This shows how the students begin with the analysis of a problem and move on to the problem-solving aspect with the ultimate goal being the project report. As seen in fig. 2.4 shows how the project work is completed alongside lectures, tutorials, experiments and field studies. This is different from a pure PBL curriculum but project work makes up half of the students working time and could take up to five months (approximately equivalent to one semester).

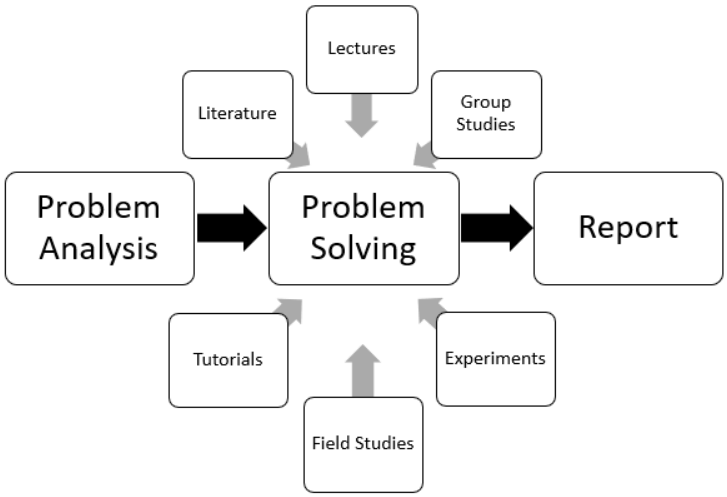


Figure 2.4: Diagram showing the processes in the Aalborg model of PBL adapted from Fink (1999) and Kolmos et al. (2006, pg. 13)

Conversely, problem-based learning models follow a similar cycle beginning with problem analysis and solving processes but they do not involve working towards a report as in the Aalborg model (fig. 2.4).

These stages were first documented by Barrows (1988) in numbered phases of self-directed learning to be incorporated throughout all problem-solving activities. These stages are taken from Barrows (1988, pg. 33-42) and have been summarised below.

1. Self-monitoring - Acknowledgement of what the students do not know.
2. Formalizing what needs to be learned - Development and categorising of learning issues.
3. Selecting learning resources - Identification of a wide variety of resources to help with addressing the learning issues.

4. Negotiating time for self-directed learning - Setting a deadline for the independent research
5. Resource critique - Assessment of the benefits or deficiencies of the resources used during self-directed learning.
6. The application of new learning - Starting over with the problem now the students have acquired new knowledge.
7. Debriefing - Conscious reflection and future integration of what has been learnt.
8. Evaluation - Self and peer evaluation of the group processes.

These stages were developed by Barrows (1988) and show the first iteration of the PBL cycle as written in numbered stages. These were originally written as the process of self-directed learning to provide tutors with prompts that can be used to facilitate the learning processes. In the years since these stages have been through many iterations and have been rephrased or reorganised to be nuanced purely for PBL. One of the most cited papers which outlines the phases of PBL is that of Hmelo-Silver (2004). A visualisation of these PBL phases as specified by Hmelo-Silver (2004, pg. 237) has been recreated and can be seen in fig. 2.5.

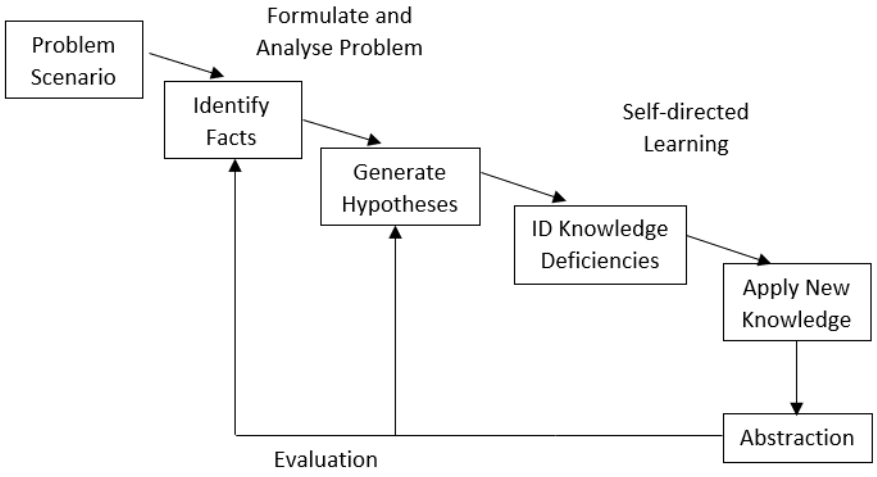


Figure 2.5: Problem-based learning cycle recreated according to Hmelo-Silver (2004, pg. 237).

Figure 2.5 shows the typical stages involved in problem-based learning, but it is depicted as a cyclical procedure where abstraction and evaluation are required to inform future

problem scenarios. This emphasises how the aim is not for the students to produce a final product but to continually transfer knowledge to the next problem scenarios.

Previously the different types of phases of PBL have been outlined to show the stages which comprise the cycle and sessions. Different PBL models are also characterised by their purpose, these have been reviewed below. This is a key element that might affect the implementation.

In terms of pure problem-based learning, five unique models have been categorised and described by Maggi Savin-Baden (2000; 2005). The details of each of these are summarised in table 2.1.

Table 2.1: Summarised description of the models of PBL as defined by Savin-Baden (2000).

Model	**Purpose**	**Key Characteristics**
I	Epistemological Competence	Requires use and management of propositional knowledge to solve narrow problem scenarios with limited solutions.
II	Professional Action	Focused on practical knowledge with problems based on realistic situations.
III	Interdisciplinary Understanding	Combination of developing skills and knowledge while working across discipline boundaries. Action oriented.
IV	Transdisciplinary Learning	Objective is to test given knowledge and take a critical stance towards subject disciplines.
V	Critical Contestability	Students learn multi-dimensional ways of knowing, exploring the underlying structures and beliefs behind problems.

The models included in table 2.1 vary in terms of their ultimate objective and the expectations of students who are working within them. The first model, I, has a focus on the subject content and the ability of students to apply knowledge when solving fairly well-structured problems.

The second model, II, has strong foundations in situated cognition theory because it is defined as *"PBL for professional action*" (Savin-Baden, 2000, pg. 128). Its main purpose and goal to become competent in the skills that will be required when working professionally. This is done by situating all problems in a realistic scenario while maintaining focus on acquiring knowledge and skills that can be transferred to the workplace.

The remaining three models of problem-based learning (see table 2.1 categorised by Savin-Baden place PBL across disciplines. This includes the movement towards interdisciplinary learning where students would be required to work within different subject domains to develop a broader knowledge base and further emphasis on critical thinking.

The data collected for this thesis observes students when working in a problem-based learning pedagogy. The module was run using a combination of PBL and PjBL. The PBL model, II: professional action, can best describe this particular implementation of the problem-based pedagogy. More information regarding the learning setting is provided in detail in section 3.5.3 on page 66.

In the defining features (section 2.3.2) one of the key elements of PBL is how the tutor acts as a facilitator to guide the PBL process. When PBL was first introduced each group would be assigned an individual facilitator (Barrows & Tamblyn, 1980). This is not always possible given class sizes are large and are still continuously growing. A solution to this was developed by Duch et al. (2001) who discuss the use of a 'floating facilitator' approach when one tutor is responsible for a small number of groups and rotates around them for the duration of a PBL session.

Woods et al. (1996) introduced a fully tutorless PBL model where the students are completely self-directed throughout the PBL process and conducted research to assess the different issues which arise in both tutored and tutorless PBL. Woods et al. found the main difference is in *"who learns and applies the tactics"*, the emphasis is on training the tutors in tutored PBL in contrast to being on the students during tutorless PBL.

The context of the data in this thesis is taken from a PBL implementation which uses a

'floating facilitator' approach. This means a tutor rotates around a number of PBL groups within the same session but is not present throughout the whole of their discussions.

2.3.4 Research in PBL

Following the emergence of problem-based learning, the majority of publications would describe PBL as it had been implemented within their own specific curriculum (de Graaff & Kolmos, 2003; Woods et al., 1997). This then developed into a more critical analysis of the pedagogy and its implementation. This more detailed research in the field of PBL will be reviewed in this section.

The early research in PBL was often on the implementation of the pedagogy within a traditional curriculum has been extensively studied and often using a quantitative methodology (Svinicki, 2007). Perhaps this is due to needing to provide evidence in favour of using problem-based learning, to help persuade both students and faculty that it is a promising and valuable instructional method. In the review conducted by Svinicki (2007, pg. 50) she calls this phase the *"initial adopters' research: proof of concept"* and, explains how the initial research conducted on PBL was descriptive aiming to explain what PBL is and to provide evidence that PBL, a pedagogical approach grounded in social constructivist theory, worked in practice (Barrows, 1996; Woods, 1996).

Research on PBL began by comparing the use of a traditional "lecture-based" pedagogy against the introduction of PBL. Such studies have so far tended to focus on student's performance. The performance has been reported through analysing the difference in student grades, on examinations or similar assessments, following a course composed of either a lecture-based or a PBL pedagogical approach (Carrió et al., 2011; De Witte & Rogge, 2016; Gurpinar et al., 2005; McParland et al., 2004; Nii & Chin, 1996; Sangestani & Khatiban, 2013).

Nii & Chin (1996) conducted a study where they found that the implementation of problem-based learning increased pharmacy students grade point average when compared to didactic lectures. Other studies report similar results when PBL has been introduced to different subject domains. McParland et al. (2004) identified that a PBL curriculum positively impacted the students' examination grades in a psychiatry

programme. Gurpinar et al. (2005) compared knowledge test scores for medical students in PBL and lectures, again it was found to favour a PBL pedagogy since test scores were higher for students in the PBL classroom. Sangestani & Khatiban (2013) assessed the learning progress of undergraduate midwifery students when using PBL against lecture-based methods. They used pre- and post-tests and found that results improved when using a PBL pedagogy. De Witte & Rogge (2016) tested PBL as an alternate pedagogy within secondary education and found the same results that PBL positively impacted student performance.

There are also some studies which argue against the positive impact of PBL reporting that PBL neither increases or decreases student performance when measuring examination grades or test scores. Carrió et al. (2011) studied the use of an interdisciplinary hybrid-PBL and reported that this had no impact on the factual knowledge acquisition when compared to lecture-based teaching. However, they do argue that PBL could give more opportunities for the students to develop professional skills such as teamwork and problem-solving.

As mentioned earlier the PBL pedagogy is based on the social constructivist theory which states that learning and subsequently knowledge acquisition is the internalisation of an individual's social experiences. Assessing the impact of PBL implementation through assessment of performance is inconsistent with the constructivist belief and does not indicate how PBL has affected other aspects of the group process.

In this same period (1970-1999) there were articles which used more subjective outcome variables to give the argument for the implementation of PBL. Rather than investigating student performance these studies showed results based on self-rating scores of student satisfaction. Albanese & Mitchell (1993) reviewed the literature in PBL and found that almost all articles reporting on student satisfaction had positive outcomes. There was a uniform conclusion that learning through PBL led to high student satisfaction scores. This is in line with another review conducted by Vernon & Blake (1993, pg. 554), who state that *"No sample was found in which the students attitudes did not favour PBL to some degree"*.

There are still more recent studies which continue to investigate the satisfaction of students when implementing a PBL pedagogy. Ribeiro & Mizukami (2005) found that all participants evaluated the PBL pedagogy positively during a case study on its implementation into postgraduate engineering education. Kang et al. (2015) conducted a comparison of three different educational modalities including two which employ the use of PBL. They found that those models which incorporated PBL had a higher student satisfaction score than the control group who were taught through "lecture-based" instruction. All of these studies, based on students satisfaction or attitude, give evidence in support of the use of PBL.

More recent studies which similarly evaluate PBL include, Helmi et al. (2016) who conducted a study using self-reporting pre and post questionnaires to assess the development of team-based problem-solving skills within PBL. They found that there was a perceived increase in these skills by participants. A case study by Warnock & Mohammadi-Aragh (2016) also demonstrated that the use of PBL significantly improved the participants self-directed learning and problem-solving. This was assessed using the performance indicators and course learning outcomes, as well as artefacts produced by students during the particular PBL course.

Following the initial phase of "initial adopters' research" came what Svinicki (2007, pg. 52) called *"the critics speak: criticisms of PBL's shortcomings"*. This describes the reaction to the initial enthusiasm and argument for the implementation of PBL in medical education from those academics who were critiquing the pedagogy. Most recognisably was Colliver (2000, pg. 259) who presented a critical overview of research in PBL, the conclusion stated that the review *"revealed no convincing evidence that PBL improves knowledge base and clinical performance"* and the author believes the theoretical basis behind PBL is weak.

Albanese (2000) and Norman & Schmidt (2000) responded to these claims by Colliver (2000) and came to the defence of problem-based learning. Both Albanese and Norman & Schmidt believe that the evaluations of PBL do not show significant cognitive effects and there may be an indication that PBL has been oversold on what it can deliver. They do however have similar concerns regarding the acknowledgement (or lack thereof) of

cooperative learning in the early evaluations of problem-based learning. Since most were evaluating the change of curriculum as a whole rather than addressing or investigating PBL on a closer level. There is a clear argument from Colliver suggesting that the implementation of PBL be abandoned due to the issues raised (e.g. the lack of theoretical background or significant evidence of its effect on cognitive effects). This is very different to the advocates of PBL who agree with some of these concerns but wish to address them and investigate further to optimise PBL rather than abandon a pedagogy which could help improve learning throughout higher education. Norman & Schmidt (2000) argue that the research in PBL should focus more on the processes in PBL rather than the resulting products.

There are more specific arguments which oppose the implementation of PBL within engineering education. For example, PBL requires substantial training for the correct facilitation as well as planning and preparation of the cases which must be contextual, open-ended with more than one correct approach (Benjamin & Keenan, 2006). This means that is not always well received by instructors especially in the engineering subject domain, it has only ever been implemented in individual modules by lecturers with the interest in new student-centred methods and not as an entire curriculum overhaul as often there are faculty opposed to it (Mills & Treagust, 2003). Another issue raised by Perrenet et al. (2000) is that since engineering knowledge is hierarchical PBL is not suitable because giving the students responsibility of their learning could lead to fragmented knowledge if the content is not properly explored as intended.

Following this phase of criticism on the implementation of PBL, there were a number of articles which called for a more in-depth and detailed analysis of what happens during PBL to more closely. This was summarised clearly by Dolmans et al. (2005, pg. 739):

> *What is needed now and in the future is research that focuses on the theoretical concepts underlying PBL and is aimed at a clearer understanding of how PBL does or does not work and under which circumstances.*

This meant there was a drive to gain insight into how to ‘do’ problem-based learning. To conduct fine-grained analysis on the collaborative details and aspects of problem-based

learning. Koschmann et al. (1997) were one of the first of these analyses which focused on one specific segment of conversation taken from a PBL session. It dissects the interaction between students and their tutor to describe what occurs within the problem-based learning setting.

In an essay written by Hak & Maguire (2000) they discuss further studies that use a similar approach to Koschmann et al.. These studies from Maastricht University and Southern Illinois University again analyse short fragments of conversation from isolated PBL sessions. Hak & Maguire (2000) claimed a need for broader description and analysis of these detailed collaborative processes.

Hmelo-Silver & Barrows (2006) conducted one particular study where they were looking to identify the goals and strategies of facilitators during problem-based learning. Here they analysed five hours of video data taken from PBL sessions and interviewed the facilitator to gather further explanation of his discourse. The results of this can inform PBL facilitators practice and has illuminated the reasoning behind the particular strategies used during facilitation. However, it does not describe or explain the discourse and strategies of the students working in PBL.

2.4 Summary

This chapter has presented a review of the relevant literature for this study. It provides an explanation of different learning theories, most importantly social constructivism which is the core theoretical background to this research. The instructional implications of social constructivism have been discussed and the problem-based learning pedagogy is clearly defined before the current research in the field of PBL is discussed.

3 | Research Design

This chapter outlines the theoretical framework and principles on which the research has been based, the methodologies and practicalities for conducting the study outlined in the thesis. This chapter also includes a comprehensive description of the data corpus that the thesis is based on including details of how and when this data was collected and managed.

As discussed in the literature review (chapter 2), it is important to try and understand the processes involved in collaborative problem-solving within the context of PBL. This is based on social constructivist principles; learning does not occur purely individually and cognitively but is also affected by a learner's social and physical environment. This knowledge led to the key decisions made in this project, primarily the use of video footage for data collection and the choice to take a qualitative analytical approach. This chapter (3) describes the alternative research designs, justifies the route that was taken and explains how it was suitable to address the research questions defined in chapter 1.

3.1 Theoretical Framework

This work is based on the theory of social constructivism; a belief that the social world can only be fully understood by the individuals involved in the activity being studied (Cohen et al., 2018; Creswell, 2014). It is believed that individuals create distinctive meanings for their own experiences and that these meanings are distinctly different for every person. Social constructivists believe that these explanations for behaviour and events are not only subjective but they are rooted in the historic and social context and are negotiated within these environments. Social constructivist researchers are aiming to develop or generate a

pattern of meaning through investigating interactions and behavioural processes among individuals within a specific context.

This thesis has already addressed the conceptual position on learning theory in chapter 2 and follows these same principles of social constructivism. This has led to the study taking a purely qualitative and naturalistic approach to examine what and how a phenomenon occurs within an authentic environment. These decisions are detailed and explained in section 3.2 of this chapter, in addition to an account of the current methods used in the field of engineering education research.

3.2 Current Research in PBL and Problem-Solving

In this field of research, a number of different approaches have been used to gather knowledge on a range of topics in the context of problem-based learning and problem-solving. These are reviewed next to inform the decision on a suitable approach to answering the research questions set out in chapter 1.

There are some studies which assess the effectiveness of a PBL curriculum by comparing students' marks when taking part in either a module using PBL or taking part in more traditional 'lecture-based' modules. McParland et al. (2004) conducted a statistical analysis to investigate the difference in examination marks of students studying from a lecture-based module and those studying from a PBL-based module. This is a popular method used to investigate the effect that a new pedagogy or intervention can have when it is first introduced and is useful to gain some idea on the result of any changes. It suggests that the products of learning are the ultimate value of any changes as they are measured using students' final examination grades or reports/assignments. However, this ignores the processes which occur during the learning experience, which is the main principle for using an active authentic pedagogy such as PBL.

Another similar approach to assess any kind of intervention (in teaching and learning) is through comparing the results from a pre- and post-test. Dalsgaard & Godsk (2007) shows an example of how this was done by administering an achievement test before and after the PBL intervention. Different to examination grades this is measuring the

increase in knowledge by testing participants before and after the PBL intervention. These methods are all focused on the outcome or result of learning - exclusively examining the performance of students participating in the study with respect to knowledge acquisition and they do not consider skill development.

One of the most well-known tools to assess the success of implementing a PBL pedagogy is to focus on the students' perceptions of their learning experience, this could be through administering questionnaires, conducting interviews with students or collecting reflective writing. This data could then be analysed using several different methodologies both quantitative or qualitative, usually dependent on the type of data that has been collected. For example, Erdogan & Senemoglu (2014) used an achievement test alongside self-reporting questionnaires, focused on self-regulation scales, to evaluate PBL in teacher education. Helmi et al. (2016) have also conducted a similar study using pre- and post-tests (quantitative instruments), collecting students' perceptions of the improvement in their own problem-solving and teamwork skills.

Conducting interviews, that can be analysed qualitatively, gives greater insight into the student experience by being able to ask for elaboration or more detail on relevant topics but it does mean that the content being captured is the students' representation of their own learning experience (according to the constructivist world view) (Cohen et al., 2018). As written by Robson & McCartan (2016, pg. 320) there are often *"discrepancies between what people say that they have done, or will do, and what they actually did, or will do"* interviews may not provide an accurate account of what happened, rather the participants reflections, an idealised perspective of events or an individual viewpoint which may differ when within a group.

Despite these approaches giving insight on both the performance and perception of students when after studying using active, authentic pedagogies such as problem-based learning, they do not consider the processes which occur during learning. They either focus on what was achieved or the opinion of participants on what (and how) content was learned, whether this was in reference to knowledge acquisition or professional skill (problem-solving) development. This has been noticed by Bridges et al. (2012) who comments on how many investigations of PBL do not consider how it is grounded in

social constructivism when developing their research design. So often these studies may not truly capture the processes which occur during the problem-solving task.

More recent examples of studies into engineering problem-solving processes utilise a method named protocol analysis, this is the production of verbal reports of individual participants thinking processes when undertaking a problem-solving task. McNeill et al. (2016) and Lee et al. (2013) use these verbal reports in conjunction with retrospective interviews regarding the previous problem-solving session. This data allows researchers to hear about the cognitive processes which occur during problem-solving, at least in the way that participants might be able to verbalise, remember, explain and reflect on. An advantage of these methods is that they do look at the learning processes and behaviour rather than focusing on the outcome of learning. However, one drawback of this method is that it is conducted in an experimental setting as an isolated problem-solving task thus it will not necessarily show the true events as were to happen in natural and authentic situations. The method would not be valid to investigate the social dimension of learning, it is focused only on individual's experience.

The research questions of the study specifically focus on the PBL context, a pedagogy that is grounded in social constructivism. There is a need to understand not only what happens when an individual takes part in problem-solving activities but to account for how a group can manage this process collaboratively.

It was therefore decided that the best method to adopt for this investigation was to observe students in a group when undertaking collaborative problem-solving during PBL tutorials. To ensure this was done unobtrusively and the data collected would be truly naturalistic the tutorial groups were video-recorded in a private room meaning the researcher did not need to be present. Cohen et al. (2018, pg. 556) expresses that *"video recording can offer a more 'unfiltered' observational record of 'natural' human behaviour in real time"*. Another practical advantage of collected video footage was that it meant the researcher could continuously go back to the data throughout the transcription and analysis process unlike traditional methods of observation. This may seem an obvious choice of data source when examining social processes (Benwell & Stokoe, 2002; Hendry et al., 2016; Imafuku et al., 2014; Valtanen, 2014; Visschers-Pleijers et al., 2006) in the context of PBL but it has rarely

been used in the field of engineering education research. Bernhard et al. (2019) have recently published a study which examines students development of joint understanding through analysis of a video recording of a group working on a design project.

3.3 Methodologies

Based on the principles of social constructivism it was decided that a qualitative methodology be adopted to address the research questions (seen in chapter 1) that the project set out to answer and analyse the rich data collected through video-recording PBL sessions.

Qualitative approaches tend to be used for the analysis of textual data and are particularly focused on understanding the whole rather than specific variables taking a holistic view on little-known phenomena (Denscombe, 2017; Marshall & Rossman, 2006). It is generally conducted on a smaller scale than quantitative approaches because even small increases in data gathered significantly increases the time that must be taken to conduct in-depth analysis.

The characteristics of qualitative methodologies strengthen the arguments for why this type of approach is suitable for the investigations being made. This is particularly relevant since the research questions are aiming to delve deeper into identifying and closely understanding the processes which occur during problem-based learning. There is however an inherent involvement of the researcher who is conducting the analysis due to the subjective nature of qualitative studies. The effect of this can be mitigated by taking a reflexive approach to the analysis. Symon & Cassell (2012) explain reflexivity as an attitude of attending systematically to the content at every stage in the analysis, it is used to ensure the researcher is aware and critical of any present biases they may hold. Further steps to increase reliability include comparing coding of different researchers (myself and my supervisors) as well as my own coding at different points in time. These procedures are elaborated in section 3.4 of this chapter.

Different qualitative approaches could be employed for analysis of the data corpus collected (details of which have been included in section 3.5). Some of these

methodologies have been reviewed here along with the justification of the chosen approach.

When starting the study for this project there was a clear focus for my work looking at collaborative problem-solving when students are introduced to a problem-based learning pedagogy specifically in the engineering education context. This led to targeted reading when completing my literature review of the field and a specific lens with which I studied the data gathered.

Thematic analysis is one of the most well known qualitative methodologies. It was first seen as a tool or process of 'thematic coding' used as part of different qualitative methods (Boyatzis, 1998; Ryan & Bernard, 2000). Braun & Clarke (2006, pg. 6) define thematic analysis as a method for *'identifying, analysing, and reporting patterns (themes) within data'*. This is a process of creating a rich description of the entire data set to get a sense of the predominant themes which accurately represent the data. Thematic analysis can be used to analyse many types of textual data, for example, interview transcripts, survey responses and newspaper articles. It is used to an gain understanding of the themes present within the textual content and to infer the underlying latent meaning.

Another similar technique that could have been applied to the data corpus was that of grounded theory. This is an inductive approach used to develop a theory regarding the phenomena being investigated (Cohen et al., 2018). The theory developed emerges from and is grounded in the data that has been systematically and thoroughly analysed. Strauss & Corbin (2015) note how the procedures involved in grounded theory provide an opportunity for a researcher to examine behaviours and topics from many different angles to reach a comprehensive explanation of these experiences.

The data required for a grounded theory analysis and subsequent theory generation varies greatly and could be comprised of several different sources. Interviews or observations are typical methods of data collection but any type of material could also be analysed using grounded theory. Hence why it would be suitable when examining the video-recordings collected for the study in this thesis. As discussed by Flick (2009, pg. 91), when adopting a grounded theory approach *"the aim is not to reduce the complexity by breaking it down into*

variables but rather to increase complexity by including context". This enables the researcher to capture the interconnectedness and naturalistic element of authentic experiences while using a systematic methodology. To ensure the generated theory is not bias and is grounded only in the data there is some expectancy that previous theory and literature be put aside.

Previously, in section 3.2, it was mentioned that the best source of data to help answer the research questions would be naturalistic video recordings of PBL group processes. Since the data provides close observation of the interactions students have during their PBL sessions, qualitative interaction analysis would also be a suitable technique. Interaction analysis is defined by Allen (2017, pg. 717) as *'a set of approaches that focus on language-in-use to understand how people jointly construct the meanings of their interactions'*. Several approaches fit within the scope of interaction analysis, a few of which have been reviewed below.

One approach to interaction analysis that could have been used when examining the data corpus is discourse analysis; the investigation of language-in-use (Gee, 2011). It is a methodology concerned not only with the explicit content of text but also its implied meaning, requiring the researcher to understand the context and read between the lines (Denscombe, 2017). Potter & Wetherell (2002, pg. 48) explain how discourse analysis is used to answer questions regarding social phenomena where the line between content and form is blurred, they regard *"talk and texts as social practices*". There are several types of discourse analysis which are difficult to distinguish from one another, in particular critical discourse analysis, Foucauldian discourse analysis, discursive psychology and conversation analysis amongst others (Wiggins, 2017). They are all focused on the understanding and investigation of discourse to differing degrees.

One particular method of discourse analysis which could be used in this project was that of conversation analysis (CA). CA was developed in the 1960s and was one of the first methods used to investigate social interactions (Goodwin & Heritage, 1990). Hutchby & Wooffitt (2008) define CA as the *'systematic analysis of the talk produced in everyday situations of human interaction'*. This method analyses conversations to further understand certain phenomena Flick (2009). This technique requires naturalistic data since it is

concerned with naturally occurring sequences in conversation.

The research questions of this study are aiming to illuminate and describe the strategies that undergraduate engineering students use during their first experience in a problem-based learning setting. It was not anticipated that these questions would lead to the development of a theory to explain these learning processes. It was therefore decided that the grounded theory approach would not be appropriate as the project was not hoping to develop a theory and because there were pre-determined expectations to my inquiries. The level of detail necessary to answer these research questions did neither require the intricate analysis achieved when employing some form of interaction analysis methodology such as discourse or conversation analysis.

Thematic analysis could be considered as the most suitable approach from those reviewed already and has the most similarities to the adopted methodology, qualitative content analysis (QCA), described below in section 3.3.1. However, since the focus of the project was to identify, describe and analyse naturalistic learning processes, which are explicitly demonstrated through the conversations students have during PBL, it was decided that qualitative content analysis (QCA) would be the most appropriate approach because thematic analysis involves higher inference processes focusing more on what can be read between the lines rather than the explicit content. Qualitative content analysis is outlined and the decision for its application in this thesis has been justified in section 3.3.1.

3.3.1 Why Qualitative Content Analysis?

Historically content analysis has been a technique applied in many research fields for a number of different purposes, it can be used to test hypotheses, generate theories or describe phenomena. It was originally used as a way of managing and transforming large amounts of text into numerical data which could be analysed statistically. This was done to make sense of the content, it was particularly used to analyse textual data gathered from media (for example, from newspaper articles and radio broadcasts) (Mayring, 2004). One definition of content analysis was given by Berelson (1952, pg. 18):

> *Content analysis is a research technique for the objective, systematic, and quantitative description of the manifest content of communication*

This denies the possibility that content analysis could be considered qualitative and was challenged by Kracauer (1952) who believed that relying solely on a quantitative exploration of data could be reducing the accuracy of the analysis by excluding crucial ideas which may only become apparent using a qualitative approach.

This was the original emergence of qualitative content analysis as a recognisable technique in its own right. The subsequent development of QCA was more ambiguous however because the difference between the qualitative and quantitative versions has become less apparent. Rather it is now just a matter of degree and does not need to be defined as either one or the other (Schreier, 2012).

A more recent and well-established definition that defends this argument was documented by Krippendorff (2012, pg. 18) who states that:

> *Content analysis is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use*

This explains content analysis as a systematic process of summarising textual data, to make meaning while taking into account the context, a process which could be either qualitative, quantitative or both. The scientific and systematic nature of the methodology is one feature agreed upon by all authors that have reviewed content analysis over the years (Groeben & Rustemeyer, 1994; Holsti, 1969; Krippendorff, 2012; Mayring, 2015; Neuendorf, 2017).

An important feature of QCA is that it helps to understand the material but only in regards to specific intentions (Schreier, 2012). The focus of the research questions is what helps direct the analysis so the researcher looks at the data with a particular lens. This is somewhat different from other qualitative methods which take a holistic view to make meaning of the data as a whole. Conducting the analysis using a specific lens may appear problematic but due to the nature of qualitative research a lot of content is produced and the data is very rich making it practically difficult to capture the overall meaning. Using a more directive approach like QCA can be an advantage when the aim of the study has a clear objective.

The procedures involved in QCA begin with abstraction and condensation of the data

keeping in mind the analytical focus of the study, this is done to reduce the data to a more manageable amount. Following this is the process of coding where units of coding or meaning units (as defined by Graneheim & Lundman (2004)) are assigned to different categories of relevance to the analysis. The main component of QCA is the development of a coding frame, this is a hierarchical representation of codes and categories identified in the data. The coding frame is what constructs the results of the study and is considered to be the heart of the methodology.

In more recent literature Hsieh & Shannon (2005) outline two main approaches towards coding in QCA, conventional and directed as well as one quantitative approach called summative. The conventional approach, previously named inductive or data-driven, is when the researcher starts working with the data and the codes are derived from the themes which emerge from the material itself. In the directed approach, known also as deductive or theory-driven, the codes are predetermined from relevant theory or literature meaning the researcher already has an idea of what to look for before working with the data making it more structured than the conventional approach. In the summative approach, the researcher begins the analysis by counting the frequency of a relevant word or phrase. The researcher then goes further by exploring the context where and when this word or a synonym is present in the data. This summative approach can be both deductive, by looking for and counting pre-determined words/phrases, or inductive, through analysing the phrases and words most frequently present in the textual data. The summative approach is that most synonymous with traditional content analysis where data was transformed from text to quantitative results.

The use of the QCA methodology was deemed the most appropriate to address the research questions (seen in chapter 1) for this thesis. As a method used to describe and make meaning of textual data, it was seen as suitable to address the objective of the thesis: to identify and describe the strategies that students use during their first experience with PBL.

QCA as a methodological approach enables the researcher to condense a considerable amount of textual data (transcripts) to a manageable amount in a systematic and scientific manner. There is specific attention on making sure that the analytical focus is kept at the

forefront of the mind at all points of the QCA process. The analysis for this study was conducted using both conventional and directed approaches to the coding. Some codes were predetermined from literature as well as informed by practice and others emerged directly from the data itself. How these analytical procedures took place in practice has been reported in section 3.4 of this chapter.

3.4 Data Analysis

The first step when analysing video data is the transcription process. This is the translation of audio to written content which can be analysed. There are different types of transcription used for particular purposes where the level of detail required may vary. The two main methods are orthographic/play-script transcription and Jeffersonian transcription (Riley et al., 2012). The key difference is that an orthographic transcription focuses on *'what'* is said transcribing the content verbatim word for word. Jeffersonian transcription is more concerned with *'how'* it was said, the process instead of the content.

Certain methodologies, such as discourse analysis and conversation analysis, require transcripts which contain a greater level of detail about how things may have been said. Such details may include a person's intonation, volume, interruptions or pauses in addition to notes on body language and gesture. A standardised method to show these particular details on a transcript was developed by Gail Jefferson and the notation has been documented by Atkinson & Heritage (1999) and Jefferson (2004). This is the modern method of Jefferson transcription. It allows the researcher to include paralinguistic and extralinguistic features which could be pertinent to the analysis.

The decision on which type of transcription to use is driven primarily by the research questions and it must be compatible with the chosen analytical method. Since the project was aiming to identify and describe the group processes which take place during PBL sessions through 'language in action' it was decided that only the content needed to be transcribed. The extra detail included in a Jefferson transcription would be superfluous to the analysis and would not have changed the coding process. Therefore an orthographic transcript was produced.

Orthographic transcription is a basic method of transcription without indication of nuances or body language so that purely the spoken content can be analysed. The transcription was completed following a method described by Wiggins (2017) using NVivo software. The key aim for transcription is that the finished transcription should reflect exactly what was said (in the raw data) and not how it should appear when written down. To translate the data as authentically as possible the researcher must not transcribe talk as what they think the learners meant to say. This would mean the data analysed is not representative of the conversations students have; it would be a misleading interpretation. It is also important not to include punctuation because people do not naturally talk in sentences, this would lead to an inaccurate representation of the raw data.

The transcription process was aided by watching and making notes on the videos before transcribing to identify on and off-topic talk - to establish periods which were pertinent to the analysis. Those which were not applicable for analysis were then ignored, these include times when:

- The tutor was present to:
  - answer questions.
  - set the group off with a new case.
- Teams were discussing off-topic content including:
  - social matters.
  - other modules, exams or assignments.
  - content that was not relevant to the case at hand.

This method was the first stage of QCA, reducing and condensing the dataset into a more manageable amount while keeping close in mind the research questions to be answered. Once some of these transcriptions were completed a pilot phase of analysis took place as recommended by Schreier (2012).

The aim in this thesis is to clearly describe the experiences of undergraduate students when taking part in problem-based learning, thus it was not necessary to develop the coding frame on an additional sample of data (not identical to material being used for the

main analysis) which would be expected if using content analysis to test a hypothesis. The material used for the pilot phase were the transcripts of videos recorded during November 2016 (the first semester of the first round of data collection). This made up a total of four hours of footage. These transcripts were read and coded manually to a set of categories, some pre-determined or influenced by literature and others purely emerging from the data itself. The explanation and justification for this have been discussed in section 3.3.1. The material was then revisited after approximately one month and on subsequent occasions by myself to be recoded to ensure reliability in the coding frame.

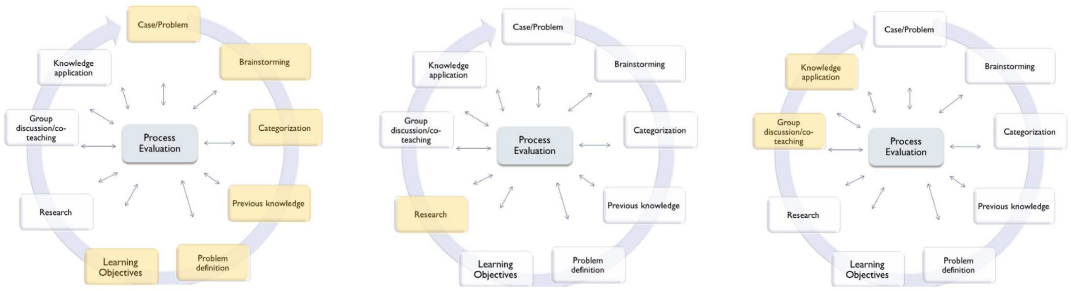
For the main analysis, the transcripts were read through several times before being coded manually with relevant utterances attached to the codes developed during the pilot phase of analysis and codes which emerge from the new data. The units of coding or meaning units were defined as each separate utterance (with the speaker's pseudonym), this was the detail that would be attached to a specific code. These codes were then transferred onto the NVivo software so that all the utterances assigned to a specific code could be collated and viewed together.

To ensure reliability, monthly data sessions were conducted throughout the study to gather input from two researchers (my supervisors) whom both have different backgrounds and expertise compared to my own to prevent any biases I might have brought to the analysis. This was so the coding could be regularly questioned, challenged and refined. To test the coding frame further my supervisors coded random extracts of the data and the results of this were discussed and compared to check for agreement, differences or any ambiguity in the codes and categories identified. This led to an adjusted and refined coding frame.

3.4.1 Coding

The original research question (developed early in the PhD project) specifically focused on how students work as a team and approach PBL when given unfamiliar problems. This primarily considers the first phase (see fig. 3.1a) in the PBL process, thus I decided to initially attend to the data corresponding to this aspect of PBL. Starting chronologically the brainstorming sessions for round 1, round 2 and then round 3 of data collection were

transcribed and coded (following the method noted in section 3.4). These transcriptions make up one data corpus for the first analysis seen in chapter 4. The findings from and observations made during the initial analysis of this data corpus then led to a development in the research questions; in addition to describing how students approach new problems, I wanted to understand how the PBL process works as a full and continuous cycle.



(a) Phase 1: Brainstorming (b) Phase 2: Research (c) Phase 3: Reporting

Figure 3.1: Phases of the PBL cycle and the stages that are incorporated into each of these phases.

The PBL cycle has been widely researched and documented by authors such as Hmelo-Silver (2004) who explains the cycle of PBL and scaffolding through the use of a PBL whiteboard where learners can keep track of their ideas and Woods (2000) who conducted a review to establish an evidence-based strategy for different stages of PBL. However, the entire process has not been observed in naturalistic circumstances.

Further exploration led to the development of three separate coding frameworks (seen in chapters 4 to 6). The first (4) corresponds to the analysis of transcripts for phase one of PBL, the brainstorming phase, as shown in fig. 3.1a for all rounds of data collection. The second and third, (5 and 6), correspond to the data for phase three, reporting phase of PBL (see fig. 3.1c) from the first round and second round of data collection respectively.

The second phase of PBL, see fig. 3.1b, makes up the time when students complete their independent research, it is not conducted within contact hours and is often completed individually rather than as a group. Since the research questions were investigating the learning processes of the group during PBL it was decided that the collecting data of this phase would not help to answer the research questions. There are also concerns on how to record this research phase in naturalistic circumstances given that the team members often work alone. Therefore the research phase has not been recorded or analysed in this

project.

Although these two phases are part of the PBL process there are different expectations on what needs to happen in each phase with one being focused on generating ideas/hypotheses or identifying knowledge gaps and the other aimed at closing these gaps and answering/evaluating the issues or hypotheses. This leads to there is great variety in the way in which these sessions are conducted, how students interact and behave during different phases hence the need for them to be analysed as separate cases.

The decision to have two separate analyses for the reporting phase of PBL was due to the learning setting changes which affected the processes in these reporting PBL sessions. These will be further discussed in section 3.5.3 of this chapter.

3.5 Data Collection

This study relies on a corpus of empirical data comprised of naturalistic video recordings of undergraduate chemical engineering students undertaking problem-based learning sessions. The data was collected in three rounds and took place between October 2016 - November 2018. The study aimed to describe learning processes in problem-based learning.

3.5.1 Ethical Considerations

Full ethical approval was sought and granted from the University of Strathclyde Chemical and Process Engineering ethics committee before participant recruitment and thus data collection took place. It is necessary to elaborate on how ethical regulations were considered and the measures taken to meet these requirements to ensure the ethical nature of the research documented in this thesis. Scottish Educational Research Association (2005) provide clear guidelines for ethical considerations when conducting educational research. Some of the key areas of responsibility and how these were addressed for this project are explained below for each particular principle.

1. Voluntary Informed Consent

    (a) During recruitment and immediately before data collection all volunteers were

informed about the aims of the research project and the processes involved in the data collection. There also were given every opportunity to ask questions from the researchers before making the decision to participate.

(b) Consent was sought and collected for all participants after having received and signed the participant information sheet (PIS) included in appendix A.1. This also asked for explicit consent to the use of images (still and video) and audio extracts to be used in presentations or published materials.

(c) The participants were told they could withdraw consent at any point during data collection, the student would then move to another group (not being recorded) and all recordings for which they were present would be destroyed. After the analysis had taken place the student was still able to withdraw consent but this would only affect the raw data and any analysis (whether published or not) would still be valid.

2. Avoidance of any detrimental effects on participants in research

(a) The students were made aware that taking part in the research project would bare no influence on their work or grades while taking part in the CP306 module.

(b) To further ensure that participating in data collection would not lead to negative impacts for the students the course leader did not view any of the raw data while the participants were still taking the CP306 class.

(c) Due to the naturalistic circumstances of the data collection the risks and potentially detrimental effects on the participants are minimal.

3. Privacy, confidentiality and anonymity

(a) The raw data was only seen by the researchers involved in its transcription and analysis, all of whom were specified on the ethics application.

(b) The content collected was watched with only the purposes of analysis in mind, all irrelevant content was ignored and kept private.

(c) Assigning a pseudonym to each participant during transcription and using only

the pseudonym throughout the analysis and during data sessions meant the participants were able to stay anonymous.

(d) When raw data (such as video extracts or still images) has been presented publicly at conferences or in journal articles the faces of participants have been blurred to ensure anonymity.

4. Data protection

(a) To minimise issues of data protection the amount of personal data collected from the participants was extremely limited.

(b) Only the names of participants were collected and then kept secure on the database only saved on an encrypted remote drive accessible only by researchers named on the ethics application.

5. Providing feedback to participants

(a) The PIS was clear that the participants were welcome to ask for feedback on the findings of the research once the project was finished. This feedback needed not to be disclosed while the participants were still involved in data collection since it could have effected the behaviour of students in their PBL sessions.

There are further regulations which must be met regarding the management and storage of data. These regulations are seen in the Research Data Deposit Policy (2014) from the University of Strathclyde. To address these from the outset of the project a data management plan (DMP) was created, a copy of which has been included in appendix A.2. The DMP includes details of the data collected, how this data will be stored and the documentation which accompanies it. This is further explained within section 3.5.5.

3.5.2 Participant Recruitment

The sample used was purposive it was specified that the participants must be part of the Chemical Process Design and Advanced IT class, a module led by my supervisor. All participants needed to be willing to be video-recorded and give permission for both image and audio to be disseminated for teaching or research. The teams were recruited

through myself and the module leader approaching the class, explaining the purpose and nature of the research project, and asking for volunteers to come forward during an introductory lecture as well through announcements on their VLE system discussion forum. The students were given contact details of myself and the module leader to express their interest or ask for further information. In total 31 students volunteered to take part in the research over the course of three academic years. These participants made up five small PBL teams (between 5 and 7 members), the characteristics of these participating teams can be seen in table 3.1. The table shows the number of students in each group, which academic year they were taking the CP306 class and the corresponding cohort size as well as indicating the method in which the groups were allocated.

The only difference for the participants was that they had to conduct their sessions in a private meeting room as opposed to the rest of the CP306 class who had their PBL sessions in an open-plan room with all groups (see fig. 3.2 for details). This was important to ensure the audio quality required for detailed transcription of the participants' conversations. The participating teams were given all the information about the research project necessary and asked to complete a participant consent form (included in appendix A.1). This also stated that if a student wished to withdraw from the study once it had begun they could move to another (non-recorded) PBL group and all recordings of which they appeared in would thus be destroyed. It was reiterated at every attempt to recruit participants that their education would not be affected in anyway regardless of whether they took part in the study or not.

Table 3.1: Characteristics of participant student groups by academic year and formation method.

Group	**No. of Students**	**Academic Year**	**Cohort Size**	**Group Allocation**
1	7	2016-2017	135	Random
2	7			
3	5	2017-2018	143	According to
4	6			
5	6	2018-2019	127	Belbin (2010)

Figure 3.2: Image to show the open plan layout for the whole cohort, demonstrating the need for participants to use a separate meeting room with the purpose of providing clear audio quality.

3.5.3 Learning Setting

An important aspect to be aware of regarding the collection of this data is the learning setting where the data was recorded, observed and analysed. Mentioned in section 3.5.1 of this chapter, the participants were recruited based on their enrolment on a specific module, CP306, as part of the Chemical Engineering Degree programme. This module is a third-year class covering the fundamental aspects of chemical process design, with a specific focus on social, economic and environmental sustainability. It runs over two semesters, from September to May and uses a problem-based learning pedagogy, throughout semester one, for learning the content followed by a project-based pedagogy, throughout semester two, for this knowledge to be applied and assessed.

Problem-based learning is an authentic and active pedagogy combines the use of small group tutorials and ill-structured problem cases to enhance knowledge acquisition and promote the development of professional skills (Duch et al., 2001; Vos & de Graaff, 2004; Davidson & Major, 2014). The model adopted for this module was defined by Savin-baden (2005, pg. 4) as “PBL for Professional Action", this model is explained in detail in section 2.3.3 on page 36. This method of instruction was first implemented within Chemical and Process Engineering at the University of Strathclyde in 2016, the first year of data collection and has not been utilised in other modules from the first or second year of the degree programme.

This implementation of PBL also uses a “floating facilitator" approach as developed by

Duch et al. (2001) where the teams only have an intermittent presence of a tutor. The participating students are described as novice with this way of working because the PBL pedagogy is completely new despite having been studying within the university and doing problem-solving tutorials for two years already.

The module leader designed the curriculum to incorporate problem cases relevant to all the important aspects of a typical chemical process design project. The cases were originally introduced in the same order as might be expected in real-life work:

- The business case and market need for designing a chemical plant
- Preliminary design
  - Material and energy balances
  - Producing a chemical database
  - Development of a process flow diagram
- Safety and environmental implications of chemical process design
- Specific equipment design
  - Heat exchanger design
  - Pump design and selection
  - Phase separator design

A visualisation of these topics is seen in fig. 3.3, this is shown to the students and this attempts to show the hierarchy of the particular topics being studied.

The order that these cases were introduced changed for the second and third round of data collection so that the first cases happened to be more familiar material, starting with material and energy balances and heat exchanger design, leaving those more unfamiliar to later in the semester when they were well practised with the pedagogy. The full detailed schedule for how the cases were ordered for every round of data collection can be seen in appendix A.3.

The module during the first round of data collection included conducting the PBL sessions

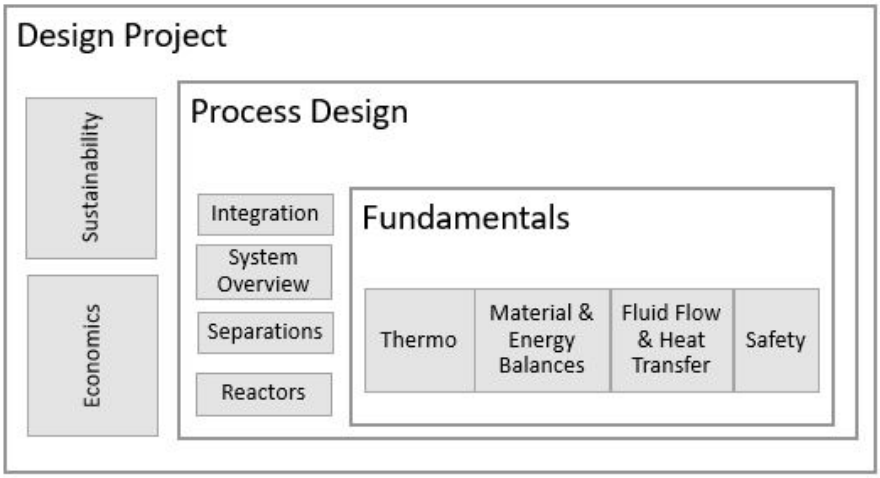


Figure 3.3: Visual representation of the content covered by the CP306 chemical process design module.

in parallel to working on a group project which included a submission in semester one and another in semester two, this meant the PBL cases were covered over both of these semesters meaning the data collection also spanned this period (see table 3.3).

The module leader then decided to change this so that the whole of the group project would be completed only in the second semester, the PBL groups would then have covered all of the required cases before they began their group project work. The same number of cases were to be studied meaning the teams had to complete more than one every week and this led to the much larger amount of filming as noted in table 3.3 and led to a challenging workload for the students to complete for a ten-week semester. This is why in 2018, the final round of data collection, the module leader amended the cases to remove and combine topics to stick to only one case per week. The full details of the scheduled cases and topics for every year of data collection have been included in appendix A.3.

The PBL pedagogy called for the completion and submission of a PBL summary form this was necessary so the teams could be given feedback on their brainstorming and learning objectives formulated as well as the summary written based on their research findings. The concept of these forms is something highlighted by both Woods (2006), who developed learning objective forms and Hmelo-Silver (2004), in the form of a PBL whiteboard. These forms included space for the teams to report/take notes or summarise

the individual research findings for one case, addressing the learning objectives they had formulated the week previous. The rest of the space was dedicated to four categories: the issues identified, description of the problem at hand, learning objectives and research responsibilities (what topics need to be investigated and who is going to do it?).

A copy of the PBL summary form has been included in appendix A.4.1, this shows as it was given to the participants from the first round of filming (2016-2017). In the academic year commencing September 2017, the summary form was adapted because the teams were asked to submit a separate summary report, which was then graded, so this part of the form became redundant and unnecessary. This time the summary form was only comprised of three sections: description of the problem at hand, learning objectives and what research will be carried out (the topics we need to investigate). A copy of this form can be seen in appendix A.4.2.

There were also several changes to the assessment schedule in each round of data collection, table 3.2 gives a clear account of the different types of assessment and their weighting for each year. The main changes between round one and round two were that the PBL summary forms were given some summative value to try to encourage engagement and increase the quality of independent research being conducted for the PBL cases.

Table 3.2: CP306 Assessment details for all rounds of data collection

Assessment Type	**Percentage Weighting**		
	2016-2017	**2017-2018**	**2018-2019**
PBL/summary forms		15	
Reflective Portfolios	10	5	
Group Presentation	10	10	
Project report(s) - (WebPA)	50	30	45
Individual test/interviews	20	30	45
Simulation Quizzes	10	10	10

The graded summary forms were later deemed to require too much time and facilitator resource so it was removed from the assessment portfolio for the academic year

commencing September 2018. Some assessment aspects had to be removed during the academic year beginning 2018 due to changes to departmental policy ruling that only two points of assessment could be included for every ten credit module. This led to the assessment profile seen in table 3.2, comprising only of one individual test, the group project report and two simulation quizzes to make up four points of assessment for the twenty credit module.

Table 3.3: Details of the amount of filming gathered for each group. A total of 80 hours of PBL were filmed and this corresponds to a total of 160 hours of footage (including two angles).

Round	Group Number	Group Members	No. of Sessions	No. of Hours of Footage	Date Collected
1	1	Annie Craig Laura Sharon Linzi Molly Callum	10 sessions 1 x 2hr weeks 1-10	15	October 2016 - February 2017
	2	Matt Katie Ryan Josh Hannah Yasmin Oliver		18	
2	3	Aaron Conor Jamal Eva Richard	19 sessions 1 x 1hr weeks 1 1 x 2hr & 2 x 1hr weeks 2-6 1 x 1hr & 1 x 2hr week 7 1 x 2hr week 8	43	September 2017 - November 2017
	4	Robert Grant Emily Adam Nick Liam		43	
3	5	Ronald Bella Carrie Norman Kadisha Lily	14 sessions 2 x 2 hrs weeks 1 - 7	41	September 2018 - November 2018

3.5.4 Video-recording

The video-recording was completed using two cameras in each teaching room to capture students from two different angles. The typical set up for the teaching rooms is seen in fig. 3.4. Figures 3.5 to 3.7 show examples of the camera angles that were set up for different rounds of filming.

Figure 3.4: Typical Room Set Up

The cameras were placed just before the students began their session, to avoid disruption once they had started and to maximise the filming time. The sessions ran for a maximum of two hours and then cameras were swiftly removed after the PBL session had ended or the group had left the room. The data was then immediately transferred onto both an encrypted remote drive (only accessible by researchers involved in the project) and a password-protected external hard-drive. The videos were then organised into folders for each session of filming and a database created to document each specific video with its meta-data. The cameras were then formatted and charged so they were ready for the subsequent PBL sessions. This procedure was the same for each round of data collection.

Table 3.3 provides detailed information for all the participating groups including the pseudonyms for each team member, the number of sessions, how many hours of footage was recorded from these sessions including both camera angles and when this data was collected.

The following subsections explain the differences between the three rounds of data

collection.

Round 1: 2016-2017

The first round of data collection started in October 2016. Individuals had already been randomly assigned to teams by the module leader before data gathering started which then required that whole teams (with all individuals agreeing) volunteered for the study. Two groups volunteered, then filming began in week six of the first semester and continued until the PBL aspect of the module finished in February 2017. Figure 3.5 shows one example of the teaching rooms and camera angles in this round of data collection.

(a) Group 1 Camera 1

(b) Group 1 Camera 2

Figure 3.5: Images to show the camera angles set up during the first round of video-recording (Group 1 has been captured as an example)

Due to a lack of battery capacity in the recording equipment often the cameras would cut out before the group had finished, this is clear from the much smaller amount of footage recorded for this round of data collection (as seen in table 3.3).

This academic year the module ran PBL sessions in parallel with two project submissions, this meant that the PBL sessions were split over both semesters and didn't finish until February when the teams then worked solely on their final project submissions. The whole PBL module included fourteen cases but due to having to start data collection midway into the first semester only 10 of these sessions were recorded.

Round 2: 2017-2018

The second round of data collection happened slightly differently after learning from the previous. This time recruitment began before the groups had been formed meaning it was individual undergraduate students that could come forward as opposed to a whole team. This time eleven students volunteered and the module leader assigned the groups as close as possible based on Belbin scores (Belbin, 2010) though it was a much smaller pool than the whole cohort. This method of group formation was used for both the whole class and the participating groups.

Included here is fig. 3.6 which gives an idea of the camera angles set up, group 4 is given as an example. The set-up is very similar to the first round of data collection and the groups were given much similar meeting rooms in which to conduct their tutorial sessions.

(a) Group 4 Camera 1

(b) Group 4 Camera 2

Figure 3.6: Images to show the camera angles set up during the second round of video-recording (Group 4 have been captured as an example)

This year there happened to be some changes in the module itself, more details of the learning setting are explained in section 3.5.3 of this chapter. The changes affecting data collection happened to be that all the PBL sessions were held in the first semester and the second semester was then wholly dedicated to the group project. This then led to timetable changes, having to complete all fifteen cases in one semester required the class to work on two cases each week. The time requirements were scheduled into three weekly sessions, one of two hours and two of one hour each.

Following the issue faced in the first year of data collection regarding battery capacity of the video cameras, I managed to acquire larger battery packs to ensure that they would

not cut out during the two hour tutorials especially because of the greater amount of recording taking place each week. In addition to starting as early as possible having the larger battery packs allowed me to collect a much larger number of hours of data for groups 3 and 4 (see table 3.3 for details).

To further improve the data collected it was also decided that a voice recorder be placed on the table in the room to reach a greater quality of audio to aid transcription, however, resource constraints meant this could only be used for one group per session of filming as they occurred synchronously (when the whole class were scheduled to have their PBL sessions).

In this round of data collection, a naming convention was now in place to make sure that all videos could be identified quickly and easily. All videos collected were added to the original database with their meta-data, this helped organise the data to check the amount collected thus far and also to track that which had been transcribed and analysed or was yet to be.

Round 3: 2018-2019

The third round of data collection was the final period of data collection. This year only six students volunteered, meaning any group formation using the Belbin roles technique was redundant and those who came forward were put together as one group. When talking to the team about the research project and gathering consent forms, it was identified that the team members actually knew one another and had worked together on previous assignments or work. They were aware that by volunteering to take part in the study they would more than likely be put together in a group.

Since there was only one team participating in the study the room allocation was easier to manage, they were given the same room to conduct their PBL tutorials for every video-recording session. A representative example of the camera angles is seen in fig. 3.7.

Similar to the second round of data collection the PBL sessions were all held in the first semester but due to concerns regarding the high workload the cases were condensed so

that the teams had only one to complete in each week. This also reduced the number of PBL tutorials that could be video-recorded. Table 3.3 gives further details on the number of sessions that were captured as well as the number of hours of footage (including both angles) that this corresponds to.

(a) Group 5 Camera 1

(b) Group 5 Camera 2

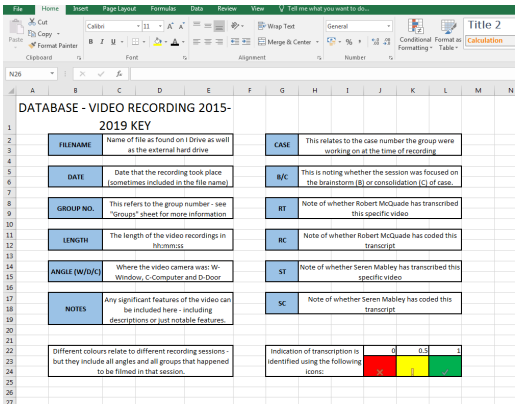
Figure 3.7: Images to show the camera angles set up during the third round of video-recording

3.5.5 Data Management

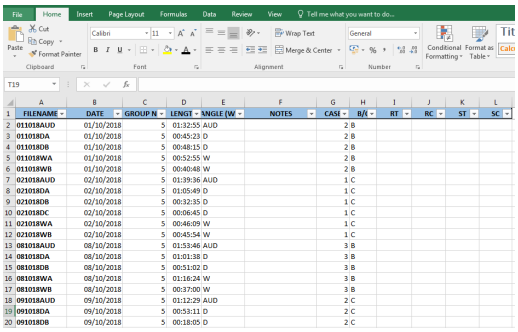
As explained briefly in section 3.5 of this chapter, the data gathered during each period of video-recording was uploaded to a password-protected external hard-drive as well as an encrypted (university) remote drive. These repositories/storage were only accessible by me and other researchers involved in the project. This is according to the universities guidelines regarding data management. This also included the creation of a database to document all the data collected and its descriptive meta-data including the date created, its length, the angle, the group, the case being studied, whether this was the brainstorm or reporting aspect of PBL and space for notes on the content of the video or concerns about the transcription. There were also extra columns added to keep track of the data that had been watched, transcribed and coded. Example images can be seen in Figure 3.8, 3.8a shows the title page for the database to give descriptions of the information included and 3.8b gives an example sheet from the third round of data collection.

3.6 Summary

This thesis has been written from a social constructivist standpoint. That is the concept that people each make individual meaning of their experiences and these meanings



(a) Title Page



(b) Example sheet - Round 3

Figure 3.8: Video Meta-data including the date the files were created, their length, the particular angle, the group, the case being studied and space on any transcription notes.

are influenced by the social environment. This theoretical framework provides an argument for the study to take a qualitative and specifically naturalistic approach to both data collection and analysis. I have outlined the current research approaches taking place within the field of problem-based learning and generally within engineering education. The emphasis of this work has so far been concentrating on evaluating student performance (from products of learning) or student perception. More recently there have been few investigations into the processes behind learning but these have yet to examine this phenomenon from a truly naturalistic perspective. In light of this, the decision was made to collect video-recordings of students when working in their PBL sessions. This provides a large corpus of unfiltered naturalistic data that can also give insight into the social dimension of learning. The methodologies that could have been employed for the analysis of this data are reviewed and the decision to use qualitative content analysis (QCA) was made. QCA enabled the author to identify and describe particular strategies/behaviour observed in the video data using a systematic approach. It is a flexible technique made valid by always considering the analytical focus of the investigation. The rigour and reliability of the analysis were supported through corroboration of the coding frame by other researchers. This chapter also describes in detail the data that has been reported on in this thesis. The data collection was completed in three rounds over the course of three academic years, from October 2016 to November 2018. This was comprised of video-recording PBL sessions of students when working in a chemical

process design module during the third year of their degree programme. A total of 31 participants volunteered to take part in the study, who made up five small PBL teams (between 5-7 students) across all rounds of data collection. A total of 80 hours of PBL sessions were recorded and transcribed then the text was subsequently analysed using the QCA methodology. The coding frames developed from this analysis gives the findings of the study and the emerging categories will be described in chapters 4 to 6 of this thesis.

4 | Brainstorming Phase of PBL

The focus of the analysis conducted for this thesis is to describe the strategies used by the students when working collaboratively in a PBL environment for the first time. To start, this first analytical chapter is more specifically focused on the initial phase of the PBL process when the participants are given new unfamiliar material (the case), asked to brainstorm and develop a problem definition as well as formulate learning objectives. This decision has been discussed and justified in chapter 3. The brainstorming phase of PBL is the first synchronous PBL session that the students have at the start of a problem cycle, fig. 4.1 shows this cycle. This analysis investigates only the sessions where the teams work on the first six stages identified in the fig. 4.1. Phase 1 is immediately prior to team members working on their self-directed learning and independent research when team members have formulated their learning objectives.

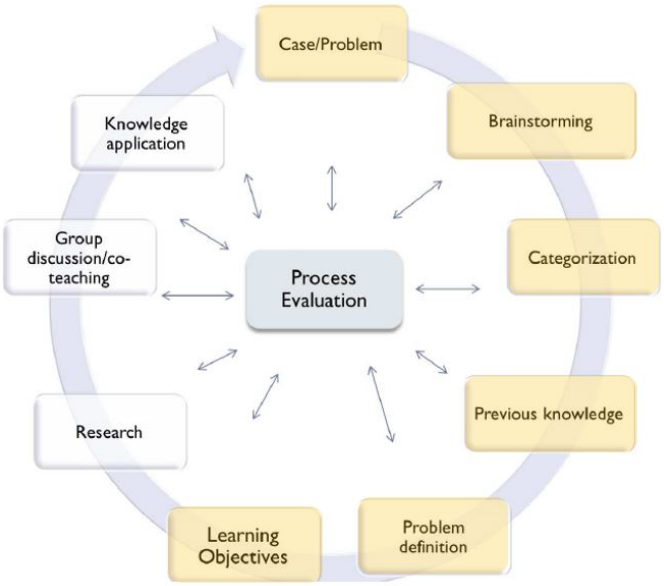


Figure 4.1: Schematic of the PBL cycle as shown to the student teams during Round 1 (2016-2017) of data collection. *(Highlighted are the stages of the cycle that refer to the brainstorming phase of PBL)*

As explained in chapter 3, this analysis has been completed using qualitative content analysis (QCA) as the methodological tool with two different approaches, the directed and the conventional. This is a combination of both deductive and inductive procedures respectively. This chapter provides a clear and distinct account of the results from these specific techniques, along with extracts from the data to demonstrate examples of the strategies employed by students and the context in which they occur during conversations between team members.

4.1 Coding Frame

A coding frame was developed when examining transcripts of the sessions covering the first phase of PBL (brainstorming). The coding frame was developed in stages, after conducting a pilot phase of analysis with a subset of the collected data. The coding frame has been amended and refined through completing the main analysis of the whole data corpus (including all participating groups discussed in chapter 3). The analysis was focused on identifying particular behaviours, techniques or strategies and describing those that were observed in the data. The final coding frame has been visualised in fig. 4.2. This shows the broader categories and the low-level codes corresponding to specific strategies identified from the students talk, these codes have been highlighted in fig. 4.2 to distinguish between those developed from known concepts (box with dashed outline) and those which emerged from the data itself (yellow shaded box with solid outline). The explanation of why there is this distinction and how specific codes were predetermined is noted more specifically through the subsections of section 4.2 of this chapter.

The findings displayed in this chapter illustrate the final and complete framework that describes what happens during the brainstorming phase of PBL. The sections have been set out to present first the strategies that were concept-driven thus predetermined before analysis took place (section 4.2) followed by the strategies that emerged during the analysis of the data itself (section 4.3). This has been done to ensure that a clear distinction can be made between the results which are grounded in and further confirm previous literature or instructional practices and those which are completely original to

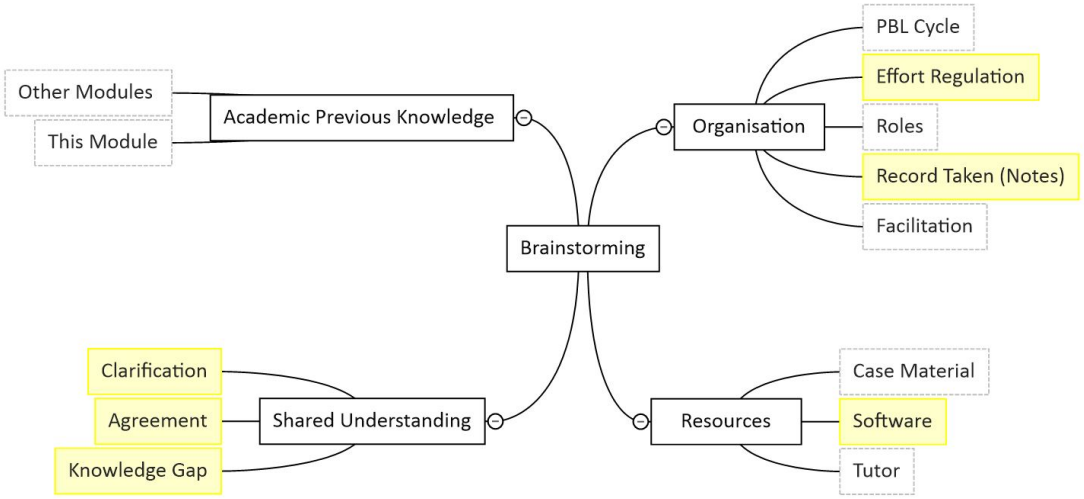


Figure 4.2: Diagram showing the full coding framework developed for the brainstorming phase of PBL. This highlights the distinction between concept-driven findings *(box with dashed outline)* and data-driven findings *(yellow shaded box with solid outline)* and how these have been categorised into wider groups *(box with solid outline)*

this thesis. These findings are then summarised and an explanation for why and how these were categorised into wider groups is provided. The detailed and critical discussion of these findings is found in chapter 7 of this thesis.

4.2 Concept-Driven Findings

This section will outline the strategies observed in the data that were somewhat presupposed to occur. The clarification for where they were derived from and why they were expected to be present in the data is specified for each of the different strategies alongside example instances of these behaviours in the conversational context.

4.2.1 Using Language from the PBL Cycle

One regular technique the students used to monitor their PBL sessions and keep track of their progress was the use of language from the PBL cycle, this included the keywords from the learning objective and summary document (found in appendix A.4) as well as those in fig. 4.1. This PBL cycle gives examples of the language used, including words such as brainstorming and problem definition. Woods (2000) has previously noted the need for some kind of structure to PBL, cycle or stages that could be followed, especially for

learners who are new to the PBL pedagogy and are trying to adapt. It was then expected that the PBL cycle (fig. 4.1) provided to students would be important in scaffolding the students problem-solving specifically given they were novice with the PBL pedagogy. This is particularly prominent since the data was collected from a module using a 'floating facilitator' approach so the PBL teams only had an intermittent presence of a tutor who might ordinarily be available continuously to help navigate the team through these different stages more naturally and gradually.

Extract 4.1 shows a particular instance where team member Aaron is using the specific language from the PBL cycle to prompt the group to start discussion of the problem at hand. In this extract group 3 were working on a case focused on process flow diagrams.

Extract 4.1: Group 3 - Case 4 Process Flow Diagrams 20:29 - 20:50 (021017W2A)

1	Aaron:	what's the problem
2	Eva:	that's equipment and that's process
3	Aaron:	let's do it as we do it
4	Richard:	right can I
5	Eva:	ok
6	Richard:	finish skimming through this
7	Eva:	I feel like we don't need to read all of this until we
8		are actually doing it
9	Jamal:	right
10	Eva:	cause this is just
11	Richard:	aye that's just
12	Eva:	the description of it yeah
13	Aaron:	that that'll form our learning objectives and issues
14	Eva:	yeah true true
15	Aaron:	but the problem is the very first start so from that
16	Eva:	mmhm

In extract 4.1 it is seen that over the course of the presented excerpt Aaron tries three times (see line 1, line 13 and line 15) to effect some response or ideas from the rest of the team by aligning what needs to be done with the expected stages of PBL. Initially, in line 1 Aaron asks "what's the problem" here he is instigating the conversation to define

the problem at hand, this is the first part of the learning objective and summary forms which the students are asked to fill out. In line 13 Aaron responds to Eva (line 7 and 12) and Richard (line 11), whom both made suggestions that the whole case does not need to be read, by confirming that topic will be something to be discussed for establishing the "learning objectives". Aaron is identifying another stage of the PBL cycle that needs to be completed. Most significantly we see that in line 15 Aaron continues this speech and orients to the fact that the "problem is the very first start". This utterance gives an indication that Aaron has assumed that the problem definition is a task which needed to be tackled and concluded before other points of discussion can be explored in more detail. Aaron has decided to prioritise the immediate task and the specific PBL expectations, as he understands them. This course of action may be of detriment to more critical and meaningful avenues for deliberation.

The example seen here is typical of those seen throughout all rounds of data collection. The PBL team use the keywords as steps with which they attempt to structure their PBL sessions. In particular extract 4.1 indicates how often the processes are followed in some particular order and deviance from this order is seen as a negative. The strategy of using the PBL cycle and associated keywords to signify a particular process task to the PBL team shows a mutual understanding of the language relevant to the unfamiliar PBL pedagogy.

4.2.2 Attempting Facilitation

The majority of problem-based learning models incorporate a tutor who is present at every PBL session to guide the team through the PBL processes. It was predicted the students might demonstrate the type of prompting expected from a facilitator themselves, especially because the literature emphasises the importance and need for careful facilitation to ensure that students work through and learn the general problem-solving procedure Barrows (1988). Given that this class was administered through PBL with a 'floating facilitator' (see section 3.5.3 or (Duch et al., 2001)) it was thought that there would be instances where some student(s) may have taken responsibility for facilitating the learning process themselves; in some ways becoming the substitute tutor for the team.

As expected from the outset it was observed that the participants often exhibited behaviour that has been characterised as facilitation of the PBL session. That is when the team needs prompting to begin, discuss, make decisions or get back on track after the off-topic talk.

This facilitation occurred regularly and it was often demonstrated by the same few individuals in each participating team. extract 4.2 shows an instance where one team member (Katie) was attempting to facilitate the PBL session discussion and get the group on task. This example has been taken from a PBL session where group 2 were discussing the design of a heat exchanger.

Extract 4.2: Group 2 - Case 12 Heat Exchanger Design 13:43 - 14:05 (310117D)

1	Katie:	erm so will we get to the case
2	Matt:	right so
3	Katie:	what are the issues identified
4	Oliver:	erm so
5	Katie:	so the simulator is not working so you need to do
6		hand calculations
7	Matt:	yeah
8	Ryan:	yeah
9	Josh:	you need to do hand calculations for a heat exchanger
10	Katie:	for a heat exchanger

In line 1 of extract 4.2, Katie starts off with asking the team: “erm will we get to the case”. This utterance gives a clear indication that Katie believes the PBL team were previously not talking about the case thus prompting the group to get back to the task at hand. Katie continues this thread in her further utterances throughout this extract. In line 3 she asks a question relating to the issues identified - a phrase used as a prompt in the learning objective and summary form (see appendix A.4.1) - and an extension of her previous question that now requires a more specific response. This appears to happen due to a little uptake by the other team members, evidenced by Matt in line 2 and Oliver in line 4 and causes Katie to continue again in line 5 where she begins to answer her own previous question.

The method of facilitation seen in extract 4.2 is representative of the many other instances

found in the data where one team member made an attempt to get the team back on track, signpost to specific tasks or move on the discussion topic. The purpose for the participant's facilitation appears to be aiming to aid the PBL process and task completion however its execution is often met with resistance by the team so it may not be furthering the teams' progress. There were times when this was seen in combination with using language from the PBL cycle as a more specific method of facilitating the learning. So the students were not only using their talk to notify the PBL team to the task at hand but at the same time signposting to, what they identify as, a specific stage of the PBL process.

4.2.3 Assigning Roles

A condition that had to be met by all of the students enrolled on the CP306 class was that they needed to assign a lead for discussion (leader) and a note-taker for each PBL session. These positions were to be rotated so that all team members had at least one chance to gain practice in these roles throughout the module. To try to prevent the leadership or facilitation of the sessions being overtaken by only one (more dominant) team member, the PBL groups were given clear instructions to create a role rotation to ensure that everyone had equal opportunity to take each role. It was thus expected that the participants may talk about the role assignation before beginning the problem-solving task.

There were some differences in how this was observed for different participating groups or during different PBL sessions, these differences have been highlighted by the two examples presented below. The first excerpt, extract 4.3, shows a very quick conversation establishing who will be taking on the roles of leader and notetaker for the current PBL session as was intended by the module leader. This extract has been taken from group 1 when they were working on the case considering equipment specification sheets.

Extract 4.3: Group 1 - Case 10 Equipment Specification Sheets 8:52 - 9:04 (170117C)

1	Craig:	alright ok so
2	Annie:	who's writing
3	Sharon:	I've got a picture of the case rotation it's got you
4		leading *((points to Annie))* and you're writing
5		*((points to Laura))*

Extract 4.3 begins in line 2 when Annie asks “who’s writing”, this utterance comes approximately eight minutes after the team were first given the case to be discussed in this PBL session. Annie’s question is then very quickly resolved by Sharon in line 3 where she explains it has “got you leading and you’re writing” while pointing at Annie and Laura respectively. This gesture combined with the names made it clear to the whole team who is responsible for these two tasks but interestingly Sharon also prefaces her utterance with an explanation of where the answer came and thus how the decision was made. When she refers to the “picture of the case rotation” and “it’s got” this is giving the control to someone or something else, suggesting that any issues with this decision would not be because of her. She is merely the messenger finding out the information that has previously been agreed by the team in the “case rotation”. This is a straightforward example of the students briefly discussing and deciding which team members take on these roles. Here this strategy demonstrates a subtle way of introducing the topic at hand and easing the team into the PBL process. If Annie had gone straight into the technical subject matter this might have disengaged some team members rather than getting everyone on board.

It was felt that another example needed to be presented for this finding to show when the teams did not quickly reach a decision on who would take responsibility for these positions; the conversation looked more like that seen in extract 4.4. This extract shows group 5 when discussing a case focused on equipment specification sheets.

In extract 4.4 there are many utterances relevant to the assignment of roles though the talk began in a very similar manner to extract 4.3. In line 1 of extract 4.4 Lily asks the same question “who is notetaker today”. She may have been hoping to have the same effect as Annie where the roles are assigned and then the team begin the PBL session but it actually leads to some back and forth between participants until a roundabout conclusion is made after Norman announces he is the leader in line 12. We see in line 5 and 6 Norman announces “I’m the leader” and explains this is because other team members have taken the role previously, the explanation provided is much more subjective than Sharon’s clear decision. Instead of taking this as true, Bella responds and contradicts in line 7 saying “someone just volunteer Lily do it” here she is asking for a team member to take on the

Extract 4.4: Group 5 - Case 6 Equipment Specification Sheets 12:57 - 13:15 (291018AUD)

1	Lily:	who is notetaker today
2	Norman:	Carrie
3	Kadisha:	don't think we can cause Carrie has all the like
4	Lily:	alright
5	Norman:	I'm the leader this year cause you *((points at Kadisha))*
6		were the leader last year and we're changing it up
7	Bella:	okay someone just volunteer Lily do it
8	Kadisha:	yeah okay that's fair
9		(1.0)
10	Norman:	I'm gonna
11	Bella:	aw read
12	Norman:	I'm the leader you can't tell me
13	Kadisha:	you can't tell him what to do
14		*((Lily laughs))*

leadership role, despite Norman having already put himself up for the role. In line 12 we see Norman repeat and extend his original utterance "I'm the leader you can't tell me" this restatement makes clear to the PBL team that he will be responsible for this position for the immediate session. This is further confirmed when Kadisha extends the previous utterance in line 13 "you can't tell him what to do", this illustrates her alignment with Norman's original statement.

These are two different methods of assigning the roles of leader and notetaker this was a requirement specified by the institution (the module leader). Across the data corpus, the assignment of these roles occurred as a way of beginning most PBL sessions and there were some times where it did take longer for the team to make a decision. It appears that this is done to ease into the PBL session without diving straight into the technical content (which the team may not respond well to) but could also be to publicise the team member in charge and responsible for the progress of the team throughout the session. This brings to mind the question of whether the students were truly aware of what leadership or notetaking role entails and that their ideas about this could be flawed. This is especially illuminated in extract 4.4, line 12 and 13, with Norman and Kadisha claiming "you can't

tell me" and "you can't tell him what to do". This implies that the named leader has more authority than the team and removes the equal status which all the team members previously had. This could lead to concerns given PBL is used to promote the development of more collaborative working habits.

4.2.4 Referring to the Tutor

The CP306 module being studied uses a PBL pedagogy with a floating facilitator approach where the PBL groups would only have an intermittent presence of a facilitator. This is quite different from most models of PBL where there is one tutor assigned to each group to facilitate during PBL sessions, providing scaffolding and more directed questioning to keep the students on track with the task at hand. Because this was not possible (due to resource constraints and large class sizes) the teams were either approached at different points in their PBL sessions to check their progress or teams would ask a tutor when they had questions or were unsure of how to proceed. Since the participants of the study were removed from the rest of the class to ensure audio quality and their sessions were conducted in separate small teaching rooms it was important that a tutor would visit the participating groups at least once every hour. It was assumed that there would be times when the groups might set aside concerns or issues they had been discussing to wait until they could speak to a tutor (someone they believed could provide an insight into their work). In this setting, therefore, it is expected that the tutor as an expert resource would be noticed in the students talk.

There were several reasons and situations when the PBL teams would mention a tutor during their conversations, including referring to asking the tutor questions or discussing their previous conversations. Extract 4.5 shows one example when the team refer not only to the knowledge of the tutor but the expectations they may hold. This has been taken from a session in the second round of data collection when group 3 are discussing a case focused on the design of fluid handling equipment.

Extract 4.5 shows the team trying to understand some details about the case and where they might be able to find the supplementary materials provided by the module leader supposedly accessed on the virtual learning environment (VLE) called MyPlace. The

Extract 4.5: Group 3 - Case 5 Pump and Line Calculations 15:42 - 16:13 (061017D2)

1	Aaron:	so maybe that gets released later on I don't know maybe
2		today she just wants us to focus on this which is
3		probably why it isn't there
4	Richard:	how do we know its actually on MyPlace
5	Aaron:	we don't its just its a bit convenient
6	Jamal:	we're assuming because she was saying she was saying
7		some aw she what was it there was there was like a
8		thing in in a previous case that basically referred us
9		to like the company website and then she was like or but
10		go onto MyPlace if that's what it says
11	Richard:	wait did she say that oh right
12	Jamal:	it was something like that and I was like oh right ok
13		so now we have to think of this as kind of happening in
14		real life

extract starts when Aaron is discussing these extra materials being released, he continues in line 2 to say "she just wants us to focus on this". By deferring to the tutor, implied by the use of 'she', this could be used to strengthen his point and opinion, assuming he also wants to focus on 'this' (the current case). Another instance where the tutor is mentioned as an external source of information for validation is when Jamal says in lines 7-10, "she was like or but go onto MyPlace". This helps to support his assumption that the material will be available through MyPlace because he has provided stronger reasoning by referencing a previous conversation with their tutor.

It was more uncommon for the teams to discuss the possibility of actively approaching a tutor as an expert source of information to find direct answers. This may have been because the students understood that tutors were not likely to give any answers but rather to make sure the students were definitely engaging as active participants in their own learning.

An extract which demonstrates how aware the teams were that the tutors were not likely to give direct answers can be seen in extract 4.6. This is also from group 3 during discussions about fluid handling equipment and its design.

Extract 4.6: Group 3 - Case 5 Fluid Handling Equipment 35:43 - 35:54 (061017D2)

1	Eva:	really we could ask what it is well not ask
2	Richard:	we could put it as an objective
3	Aaron:	may as well ask like at the end of the day all she does
4		is turnaround and say I'm not telling you but if you ask
5		and she tells you you've figured out something so

In extract 4.6 Eva is the first to suggest "we could ask" in line 1 but is quick to say this was not quite what she meant and is corrected by Richard in line 2 who recommends the team "put it as an objective". This shows that they understand if they identify a question that the team themselves can not answer this can be formulated as a learning objective to be researched. The PBL group do not automatically assume they can ask the tutor for an answer. This sentiment is further indicated by Aaron's response in lines 4 and 5, "all she does is turnaround and say I'm not telling you" this emphasises their understanding that the tutor will be reluctant to give an answer and not afraid to say so; this is an important quality for PBL facilitators. Despite the understanding that the tutors will not explicitly answer the PBL teams questions, the group here still show that there may be value in approaching the tutor as a resource. These examples are shown here demonstrate how the tutor is referred to in talk; either used as a way of strengthening a point since it had been mentioned by the tutor previously or because the team are discussing the possibility of approaching the tutor as an expert source of knowledge. The tutor is one of the most convenient resources that the teams can utilise, it could be that the students invoke the tutor since they see this will make their task easier. It could also indicate the team members are still heavily reliant on the tutor's guidance and are not displaying the characteristics of active and autonomous learners.

4.2.5 Mention of Case Material

A key claim made for the benefit of introducing a PBL pedagogy is that it provides the freedom and environment for undergraduate students to develop and improve their self-regulation (Hmelo-Silver, 2004). In order to become expert in problem-solving, it is necessary to have the skills needed to monitor and self-direct learning processes, this includes taking the initiative to find the relevant resources to gather the information

needed to solve the task at hand. This section describes how the teams turned to the case material itself as a source of information. This is the easiest resource available to the teams and is invaluable for the students to get a grasp of the problem at hand. However, they have been purposely designed to be unfamiliar, open and ill-structured cases that should take a week for the team to research and solve. There is a broad scope which requires the students to partake in critical and meaningful discussions, to look beyond their own ideas and the information they have in front of them. Examples of when and how the team use the case material in their conversations have been expanded on below.

Extract 4.7 shows an instance where group 2 have been working on a case focused on the environmental impacts of chemical process design and how these might be mitigated or prevented in practice.

Extract 4.7: Group 2 - Case 6 Environment 8:05 - 8:26 (071116A)

1	Josh:	suppose then this we could look at legislation difference
2		between
3	Hannah:	countries
4	Josh:	countries yeah
5	Katie:	yeah but the way they've worded it in this they're saying
6		use the legislative framework to make a list of like
7		environments that you can have and why you would or
8		wouldn't have them
9	Josh:	oh ok yeah
10	Katie:	its what that's saying there
11	Josh:	aye we'll ask I suppose

In line 1 Josh starts the conversation about "legislation difference" and Hannah continues this track in line 2. Josh's repetition in line 3 gives the indication that he agrees or that this might mean they have reached some conclusion. However, in lines 5, 6 and 7 Katie begins what appears to give a counter-argument (by starting "yeah but"). In this utterance, she states "they've worded it in this they're saying use the legislative framework", this positions her idea as belonging to someone else. She is strengthening her argument by referring to what and how something has been written in the case itself rather than as her own opinion. Calling on the keywords in the case is incredibly useful for the team to gather a

clear picture of what the task is relating to, here it is being used by members of the team to help clarify what is truly being asked of the group. This discussion is concluded by Josh in line 11 when he says “aye we’ll ask I suppose”, a decision has now been made to seek resolution of the issue by asking the facilitator, who is an expert, rather than continuing the conversation between themselves.

There are also occasions where team members refer to the case worksheet to begin the brainstorming process or the PBL session itself, extract 4.8 is one such case. This is an extract from the beginning of a session where group 1 were discussing the design of a phase separator.

Extract 4.8: Group 1 - Case 13 Phase Separator Design 1:05:06 - 1:05:23 (070217B)

1	Sharon:	so has this all got to be done like hand calculations
2		again cause it doesn’t say otherwise
3	Molly:	maybe like stream calculations
4	Sharon:	it just says we we need to decide the minimum
5		specifications on calculations but it doesn’t say whether
6		or not
7	Molly:	S401
8	Annie:	what is S401

Sharon asks in line 1 “has this all got to be done like hand calculations” to start the discussion about the task at hand, she continues to say “cause it doesn’t say otherwise” in line 2 and this is when she is referring to what the case material (“it”) is or is not stating. After Molly has responded in line 2 with her own suggestion of what the case is asking, Sharon starts again in line 4 mentioning the case material “it just says we we need to decide”. She is verbalising the content which the team may or may not have already read themselves. This is a simple strategy to open a conversation about what the information and keywords from the case are implying.

This section outlines examples of how the students use the case material in their discussions. Here it has been shown to be a technique used to validate and reach consensus on ideas since it is backed up by a resource or as a prompt to begin conversations regarding the meaning of the task at hand.

4.2.6 Activating Academic Previous Knowledge

There are a number of papers that discuss the need for learners to activate their own academic prior knowledge during problem-solving and that using a PBL environment can help promote the activation of relevant prior knowledge (see Dolmans & Schmidt (2006); Loyens et al. (2015); Schmidt (1993); Schmidt et al. (2011)). This led to the expectation that it would be likely the teams of this study would in fact orient to the activation of their own prior knowledge when working in the PBL environment. Of course, there is an argument to say that academic prior knowledge could be anything that the learners say with any relevance to the content of the current PBL case. To make explicit what was meant by the activation of academic previous knowledge, the utterances that were coded under this heading were references to mutual experiences since the participants might not have worked together before but have all studied on the same degree programme for two years. The students were not only activating their own previous knowledge but then making the rest of the team aware of this meta-cognitive process, with possibly the effect of helping them to also reach this same point. There were two different levels at which this was noticed, when the participants refer back to previous cases within the process design module (CP306) and when they recall content from previous modules studied earlier in their academic programme. Examples of both are included below.

From the Current Module (CP306)

The cases themselves were designed by the module leader to follow a story from start to finish of an intern working in a chemical processing company. This meant they were connected to one another and it was expected that the participants may call upon the earlier cases to help them while working on the current problem at hand. Whether this is regarding the content of the previous cases and how this might be relevant to the current case or the group processes involved in PBL. This was particularly prominent for the first round of data collection when the cases themselves were framed solely around the process of ammonia production throughout but it was demonstrated by several students across all the participating teams.

One example of this finding is seen in extract 4.9, group 1 were discussing a case focused

on the environmental impacts caused by chemical processing. This case was immediately following on from a similar case focused on understanding the safety concerns around ammonia production (see appendix A.5).

Extract 4.9: Group 1 - Case 6 Environment 23:13 - 23:56 (071116B)

1	Annie:	seems to me like last week but with
2	Molly:	like waste products and stuff
3	Sharon:	I know
4	Molly:	I think cause its the environment half of their stuff
5		like emissions into the air and anything or yeah
6	Sharon:	and like stuff can't happen near houses whatever
7	Annie:	emissions
8	Molly:	what do you mean happen near houses
9	Sharon:	like the fact that the plant is like near
10	Molly:	right so its kind of like safety layout as well
11	Sharon:	yeah

The extract begins when Annie, in line 1, says "seems to me like last week but with" this gives reference to the topic that the team covered in last weeks PBL session. This statement makes clear to the team that Annie has made some connection between this case and the topic they have just been researching (safety within process design). Annie is sharing and in doing so aiding the team's progress by helping the other team members to make this same link, which is important since a key aspect of problem-solving is the ability to link relevant aspects of a learner's previous knowledge to the current topic. Team members continue to elaborate on this topic, identifying how the case might be similar to the last week's. Molly then questions Sharon's idea in line 8, "what do you mean happen near houses". She receives only a short and vague response from Sharon in line 9 before Molly provides her own interpretation stating in line 10 "right so its kind of like safety layout as well". Safety layout happened to be a learning objective that the team addressed in their previous PBL session (covering the reporting phase of PBL), this information along with her ending with "as well" shows she is extending and further specifying how this topic might be similar to "last week". This utterance is another instance where Molly is making connections to prior cases they have studied and verbalising this for the rest of the team

to benefit.

From Previous Modules

The majority of the concepts that the students are introduced to in this module are building upon the modules that they have studied in their first two years of the whole degree programme. Often these cases are asking the teams to apply their own knowledge in a different context, which will require the learners to conduct some investigation into what they do not already know. This should provide a basis for them to connect and link the cases to subjects they have already learnt and been examined in. This did happen but it rarely occurred spontaneously as more often it would be after the PBL team had spoken to a tutor who suggested to think back to a particular module.

Extract 4.10 shows one instance of how group 4 made the link between the current case and previous modules they had all studied without assistance from a tutor. This has been taken from a case where the teams were tasked with the development of a process flow diagram.

Extract 4.10: Group 4 - Case 4 Process Flow Diagrams 55:48 - 56:08 (021017AUD1)

1	Emily:	I need to look at all this I can't remember any of this
2		I've got my CP101 notes somewhere *((Emily laughs))*
3	Adam:	that's what I'm doing too copy CP101
4		*(unclear speech)*
5	Grant:	I I am mildly concerned this year how my like second
6		year knowledge is gonna like you know
7	Adam:	should be okay hopefully
8	Grant:	but I'm sort of hoping it comes back more and more
9		over time because like

In line 1 and 2 Emily announces "I can't remember any of this I've got my CP101 notes somewhere" this is a very explicit and clear reference to the module CP101 which the team members all studied during their first year. Adam then agrees and repeats this connection in line 3 stating "copy CP101", from both of these team members mentioning this course we can see that they believe it is necessary and relevant for them to look back at that module content as a possible source of information. By communicating this to the whole

team it can help them also make these connections to ensure that everyone is aware and has the same subject in mind. It is a method for the team to reach a common ground as well as providing a platform for the group to move forward with the problem at hand. To further analyse the excerpt we see that Grant discloses, in line 5 and 6, that he is "mildly concerned this year how my like second-year knowledge is gonna like you know". This utterance could be an indirect way of Grant implying that he is unsure of the module that Emily and Adam had referred to while also concerned about his knowledge covered during his second year on the degree programme.

The indication that the learners are activating their own previous knowledge is one of the promising findings observed in the data since one of the key aspects of PBL is that the students are developing life-long learning techniques to aid their future transfer of knowledge. This is demonstrated from how the team members have identified their prior knowledge and are working to apply this in a different, more complex context. A particularly important skill since the aim of this model of PBL is to enhance professional enculturation when graduates begin work in the engineering industry.

4.3 Data-driven Findings

This section is now focused on the findings that emerged solely from the data itself, that is they were not pre-determined from either literature or expectations from the use of the pedagogy before analysis took place. A description of these different strategies has been included in addition to examples of instances that demonstrate them in use during PBL sessions. These findings emphasise the original contribution that the thesis provides to the research on PBL within engineering education.

4.3.1 Effort Regulation in Talk

In all of the rounds of data collection, the teams demonstrated an awareness of the level of effort that might be required to solve a given problem-case. This regulation or monitoring of the group effort was observed in different manners, two particular methods have been presented in extract 4.11 and extract 4.12 and are described below.

In extract 4.11 group 3 have just been introduced to a case focused on the selection of production route and rationale behind this decision. This particular excerpt shows the group working to clarify the task at hand and define the scope of the problem.

Extract 4.11: Group 3 - Case 8 Process Route Selection 1:14:10 - 1:14:33 (161017AUD2)

1	Eva:	what what is rationale
2	Jamal:	it means that its a reason its a reason why
3	Eva:	so do we just look up these and decide which ones best
4		is that what it is
5	Jamal:	please god let it just be that
6		*((laughter))*
7	Eva:	we need to provide processing options describing
8		technical alternatives
9	Jamal:	we need to say why but
10	Richard:	it doesn't seem too difficult
11	Jamal:	see if thats all we have to do we just have to say why
12		its better

It begins in line 1 with Eva asking the question, "what is rationale" answered by Jamal in line 2. The discussion about the amount of effort required for this task starts with Eva in line 3 when she says "do we just look up these". The use of the word "just" orients to the idea that this task will not be difficult or may not require particular effort from the team. Jamal gives a very positive response to this proposal saying "please god let it just be that" and the same notion is reiterated by Richard in line 9 "it doesn't seem too difficult". When this extract begins the team have only been discussing this new case for a few minutes, yet it appears they have already decided what the task consists of and that it will not be a difficult problem to solve. This is quite surprising to hear given that there has been little critical discussion about the material and the steps required before they could actually identify which production route would be best. They have assumed their first idea was correct and that the case is simple to complete. This strategy could also be used to downplay the complexity of the task for the purposes of self-efficacy.

One other distinct method of regulating the team effort occurred typically towards the end of these brainstorming PBL sessions when the team was deciding how to structure their

own independent research. Extract 4.12 is presented to show how a PBL team would make attempts to split up the workload between its members. This example has been taken from a session where group 5 were discussing the creation of a chemical database.

Extract 4.12: Group 5 - Case 4 Chemical Database 56:59 - 57:11 (151018AUD)

1	Norman:	should we divide who's doing what
2	Ronald:	yeah we just need to divide it up
3	Kadisha:	to what
4	Norman:	so say safety we can just divide them up for these type
5		of problems
6	Bella:	doesn't everything fall in together anyways
7	Carrie:	yeah
8	Ronald:	yeah
9	Norman:	yeah but you can just divide it someone can look at the
10		like chemical properties

In line 1 Norman proposes that the team "divide who's doing what" and Ronald agrees in line 2, "we just need to divide it up". On the other hand both Kadisha and Bella show reluctance to agree to this course of action, in line 3 and 6 respectively. Bella clearly specifies, in line 6, that "doesn't everything fall in together anyways" indicating it would be difficult to establish separate topics to be researched. Norman replies to this in lines 9 and 10 giving an explanation of how he would suggest they split up the learning objectives.

The example extract 4.12 shows another method of how the effort required of the team is monitored and negotiated through the learners' conversations. The strategy led to each team member only having to research one or two particular topics identified as learning objectives. It is described as the process of 'divide and conquer', it is well-known but it is intriguing to find this being used in the context of problem-based learning when the teams are encouraged to work collaboratively to solve problems.

4.3.2 Record Taken (Making Notes)

It was seen in the data that the teams felt very seriously about what they were asked to write down or record during their PBL sessions. In chapter 3 it has already been discussed

that the students have a learning objective and summary form to submit at the end of every PBL session. This included the problem definition and the learning objectives that the teams have formulated to inform the research for the upcoming week. This is read by the module leader after the session and the teams are given feedback on their learning objectives the following day. It emerged from the data that students used their talk to portray how this written record of their PBL sessions needed to be carefully thought about. Often the participants would discuss in detail the content before deciding what would be allowed to be recorded on the summary form.

Extract 4.13 gives an indication of the type of conversations that happen when the teams are deciding what to include in the summary form and when they should take notes of their discussions. It is taken from one of the first sessions where group 4 were discussing heat exchanger design.

Extract 4.13: Group 4 - Case 3 Heat Exchanger Design 28:09 - 28:39 (220917D1A)

1	Nick:	is anyone writing on that by the way
2	Emily:	I I think we should leave that until we've got a concrete
3		plan in our head
4	Grant:	yeah
5	Nick:	alright I just wondering about time its only
6	Emily:	but I will I would literally rather take it home and do it
7		myself and be truly
8	Nick:	you can't
9	Emily:	you can
10	Nick:	you need to give at the end of this
11	Emily:	do you
12	Adam:	yeah I think so remember at the end she takes them away
13	Emily:	well we'll do it like
14	Grant:	it takes like 5 minutes
15		*(unclear speech)*
16	Nick:	at ten to we'll start doing that we can still talk while
17		someone writes that

In line 1 Nick makes the first orientation to the summary form when he questions "is anyone writing on that". The response he receives from Emily in lines 2 and 3 highlights

clearly how important the summary form appears, by saying “we should leave that until we’ve got a concrete plan in our head”. She believes that the team needs to bring together their thoughts and discuss them before writing anything down, as a way of mitigating the number of mistakes on the form. Emily is also aware that the team may change their mind about what the problem at hand actually entails. After Nick suggests that they may not have time, in line 5, Emily replies with an even more fervent stance stating, in lines 6 and 7, she would “literally rather take it home and do it myself and be truly”. This implies that Emily is incredibly concerned about making sure that the summary form is neat and correct, clearly focusing less about what themselves as learners need to do and more about what the tutor might be wanting to see.

The reason for the summary forms is to help the students scaffold their own sessions through the PBL process and to give them feedback to ensure their research activities are focused on the intended subjects. It is a tool designed for the students to make the most of their time and should not be completed with the purpose of pleasing the tutor. This extract has been taken from the transcript of a PBL session early on in the semester so the need for the team to be right could be more obvious here due to their uncertainty with the PBL pedagogy.

4.3.3 Discussing Software

One unexpected resource that the participants used to help and add to their discussion was mentioning features of specific software, such as Aspen, Visio or Excel and whether it might be relevant to the case at hand. This happened more often for cases which would have been aided by the use of software and thus discussing this course of action would be very relevant to the task at hand. It was however sometimes just used as another source of information to help them understand the current problem case.

The first example demonstrates one instance where group 1 used software to help them make meaning of the case. extract 4.14 shows an excerpt of conversation about a case focused on the design of a heat exchanger, this included an equipment specification sheet with some of the details necessary for the team to carry out the calculations. They have seen a similar sheet (TEMA) when learning to use the software Aspen earlier in the

semester.

Extract 4.14: Group 1 - Case 12 Heat Exchanger Design 18:29 - 19:09 (310117B)

1	Annie:	oh this is the TEMA sheet like on Aspen
2	Molly:	mmhm
3	Laura:	are we going to have to use aspen this week then
4	Linzi:	well she said the other day
5		*(unclear speech)*
6	Annie:	so hand calculations
7	Molly:	so what are we thinking
8	Annie:	I don't know minimum specifications and all detailed
9		calculations by the end of this week
10	Laura:	probably to do with a pump like about how
11	Annie:	its a heat exchanger
12	Laura:	yeah
13	Annie:	its probably heat exchanger design

The extract begins with Annie in line 1, she first mentions how the case material is similar to the "TEMA sheet like on Aspen", Aspen is the simulation software which the students were learning to use alongside the cases. Here Annie is trying to place the data they have been given to a familiar setting. This might help the PBL team to make sense of the information they have been given, by translating it to the data they have previously worked with on the Aspen software. This leads to Laura's question in line 3 "are we going to have to use Aspen this week then", this indicates that Annie's prompt regarding the Aspen software has resulted in more enquiries about the course of action to solve this problem case.

This reference to an external source of knowledge and other aspects of the class has determined the direction that the conversation was then taken and has helped the team to place the case in a more familiar context.

4.3.4 Establishing Shared Understanding

During the coding, another strategy which emerged was the method in which the groups attempt to reach a shared understanding. This is the ultimate goal of all of the techniques

that help the PBL teams to progress but here are some particular conversational tactics that the learners apply to establish a shared understanding. Examples of these have been included below.

Identifying the Knowledge Gap

It is well-known that part of the typical problem-solving process is to initially identify what is known and unknown. This is particularly important in PBL when students are working in a group; because it might be that one person does not know but another team member has experience in the particular matter at hand. More work needs to be done for the PBL team to establish as a collective and through conversation, the knowledge they have and the information which is lacking. This then gives the group a starting point for what research must be done.

An example of when the teams do identify a gap in their knowledge is presented and described below in extract 4.15. Here, group 4 are talking about what the current case is asking for, they are attempting to define the task at hand including the boundaries they might be able to put in place. They are not only thinking about what the case involves but also what it may not involve. This case is relating to the production of a block flow diagram and a process flowsheet.

Extract 4.15: Group 4 - Case 4 Process Flow Diagrams 1:19:27 - 1:19:46 (021017AUD1)

1	Nick:	I've just noticed I don't think we actually need
2		to do a PFD
3	Grant:	no tha-that's the thing it says process flow sheet
4	Nick:	it says we nee-yeah we need first thing is the block flow
5		and also the process flow sheet for the preparation of the
6		process flow
7	Grant:	which is why I'm confused because
8	Adam:	yeah we don't know what a process flow sheet is so
9	Nick:	it doesn't say we have to do the process flow diagram
10	Adam:	yeah
11	Grant:	so all we need is the block flow diagram which is easy
12	Nick:	ehh and a process flow sheet

In line 1 and 2 Nick states “I don’t think we actually need to do a PFD”, Grant agrees in line 3 and Nick continues his utterance in line 4, 5 and 6 where he gives further explanation to justify his first suggestion. Here the two participants are working to identify what is not relevant to the case at hand. In line 7 we see the first time that a student has expressed some uncertainty when Grant says “which is why I’m confused” he is using a personal pronoun because at the moment he only knows this as a feeling belonging to himself and a member of the team might be able to expel his concerns and explain these concepts to him. However, the response from Adam in line 8 repositions this gap in the knowledge as a group concern by making the statement “we don’t know what a process flowsheet is”. In this excerpt, there is no immediate reply to his admission as the other team members go back to the case in hand thinking instead about what they can complete or do already know. Nick reiterates, in line 9, that “it doesn’t say we have to do the process flow diagram” this is a reformulation of his first statement in line 1. Meanwhile, Grant goes back to what appears a more comfortable subject in line 11 saying “all we need is the block flow diagram which is easy”. It is only in line 12 of the extract when Nick refers back to the concept of a “process flow sheet” which Adam previously admitted was unknown. There is no immediate resolution of this issue but due to recognising this gap in knowledge a decision was made to formulate a learning objective to establish what is a process flowsheet. This discussion and decision making happened much later in the session thus was not included in the extract presented here.

Looking for Clarification

In the process of reaching a shared understanding, the students regularly ask questions to get other team members to clarify or elaborate on their ideas. They may also repair and reformulate their own ideas by clarifying something they had actually first mentioned or asked the group about themselves. This was a promising finding since the teams would actually question one another about their ideas before making final decisions which suggest there were some deeper level discussions about how the problems could have been defined.

One example of when group 2 were making these clarification statements or questions

can be seen in extract 4.16. In here the PBL group are working on a case based on the development of a heat exchanger network as a method to reduce energy requirements.

Extract 4.16: Group 2 - Case 14 Heat Exchanger Network 24:58 - 25:12 (140217B)

1	Matt:	do we have to do this on aspen or do we need to do the
2		hand calcs
3	Hannah:	hand calculations
4	Katie:	you'd use a spreadsheet would you not
5	Matt:	'perform some preliminary calculati'
6	Katie:	it wants you to use your own spreadsheet
7	Matt:	ok

In line 1 and 2, Matt begins the discussion asking the team "do we have to do this on aspen or do we need to do the hand calcs". By giving these two options it is clear that Matt has already given some thought to the definition of the task itself and is now more concerned with how the team might be able to tackle the problem. Hannah responds and recommends they use "hand calculations" in line 3, but this is somehow contradicted by Katie. In line 4 Katie elaborates on the first options from Matt when she says "you'd use a spreadsheet would you not" here this is positioned as another question with the addition of "would you not". It appears that Katie has not made her mind up about what needs to be done and is seeking further clarification from the team. At this point Matt refers to the case material, in line 5, searching for more information to help the team but Katie interrupts in line 6 with "it wants you to use your own spreadsheet". This is answering her original question from line 4 where she seemed hesitant in her suggestion but in line 6 uses the case material as 'it' to confirm the idea. Although when aiming to establish a mutual understanding for the PBL group she was hoping or expecting the first statement would elicit alignment from the other team members earlier but the lack of response meant she felt she had to elaborate herself. Matt replies to Katie with just "ok" signifying that he agrees with her, this is the result of the work done by the team to clarify the meaning of individual team members comments.

Similar sequences such as this are seen across the data corpus and are sometimes much longer before the group reach some mutual understanding or agreement. It is reassuring

to see that the teams appear to discuss thoroughly the problem case before clarifying the task and that it is not always just interpreted on a surface level.

Formulating Agreement

The final strategy in the category is how the teams signify and make clear when they have reached some agreement, this might be regarding the definition of the problem when formulating learning objectives or deciding on questions to ask the tutor. The way in which people express their agreement has different forms too, two examples have been provided and discussed below.

Extract 4.17 shows a longer excerpt from one of the PBL sessions where group 5 were discussing the design and selection of fluid handling equipment.

Extract 4.17: Group 5 - Case 2 Fluid Handling Equipment 44:53 - 45:16 (021018DA)

1	Bella:	did you say the pump increases decreases in velocity and
2		then as soon as it gets out the water increases its
3		velocity before it goes into the
4	Kadisha:	no it's the other
5	Bella:	huh
6	Kadisha:	no it incre it goes in it increases velocity and as it
7		comes out it goes through a diffuser which decreases
8		velocity
9	Bella:	alright I thought there was expanding
10	Kadisha:	that is why with the diffuser
11	Lily:	yeah yeah that sounds
12	Kadisha:	cause it expands the area
13	Ronald:	cou can we put
14	Bella:	alright
15	Ronald:	as the learning objective why the diffuser's here

In extract 4.17 the team were discussing the purpose of a diffuser that appeared in a schematic included in this weeks case material. It is noticed here that Kadisha is more knowledgeable on the particular topic as the questions asked are being answered exclusively by herself. To specify, Kadisha is working to explain herself in line 4, "no its the other", in line 6 and 7, "it goes in it increases velocity and as it comes out it goes through a

diffuser" and in line 10 "that is why with the diffuser". These are all in response to prompts or questions from the team member Bella, this sequence is another example of the teams working to reach clarification on a specific topic as explained in section 4.3.4.

Although the focus of this strategy is how the students signify agreement on a particular idea this alignment is not reached until Lily joins the conversation. In line 11 Lily says "yeah yeah that sounds" unfortunately she is cut off but this implies she is agreeing with Kadisha's previous statement. It also prompts a slightly more positive response from Bella, who was the team member previously unconvinced, she states "alright" in line 14. This is the point at which Ronald joins the discussion with his recommendation "can we put ... as the learning objective why the diffuser's here" (see across lines 13 and 15). This shows that although he agrees with the other team members he believes it to be a point which needs more exploration. This is quite a lengthy sequence which requires a significant amount of work before the group reaches a conclusion which allows them to move on.

The following extract shows a more explicit instance where PBL team members communicate their affiliation. Extract 4.18 has been taken from a PBL session where group 3 were analysing a problem case based on identifying the environmental impacts of chemical process design to determine how these could be prevented or mitigated.

Extract 4.18: Group 3 - Case 13 Environment 11:46 - 12:13 (031117AUD1)

1	Jamal:	and we need to produce a framework for possible measures
2		for addressing potential environmental impact
3	Conor:	mmm
4	Aaron:	is that two separate things or is this gonna be part of
5		the same document
6	Jamal:	well in this sentence it says one thing but its like it
7		is two things it is two things
8	Eva:	yeah is it the framework for the measures as well or just
9		the measures
10	Jamal:	yeah I think so or oh the possible measures well you well
11	Eva:	we need you to produce a framework for an effluent summary
12		report and possible yeah I think you are right

In Extract 4.18 Jamal begins by making an announcement "we need to produce a

framework", Conor considers this but does not really respond (see line 3) and Aaron asks Jamal to elaborate with more information in lines 4 and 5. The point at which the team express they have reached an agreement is in line 11 and 12, with Eva saying "yeah I think you are right". This is a very direct declaration to demonstrate how she is agreeing with Jamal's suggestions and shows an unusual manner in which this is observed in the data.

4.4 Summary

To summarise this chapter has described in detail the findings from the analysis of the brainstorming phase of PBL. This includes the strategies which were predetermined and those which emerged naturally when examining the data itself. These codes can be seen in table 4.1 and follows the same categories previously visualised in fig. 4.2.

Table 4.1: Summary of the strategies identified from the analysis and how they were further categorised into larger groups.

Strategies			
Organisation	**Resources**	**Academic Previous Knowledge**	**Shared Understanding**
PBL Cycle	Tutor	This Module (CP306)	Knowledge Gap
Facilitation	Case Material	Previous Modules	Clarification
Roles	Software		Agreement
Effort Regulation			
Record Taken			

The four main categories are how the students organised their PBL sessions, the external resources that students used, the activation of their own prior knowledge and how the way the participating teams worked to establish a shared understanding. These categories comprise of a number of strategies that are all related to a wider theme. Some categories were developed with a combination of concept-driven and data-driven findings, as can be seen by those highlighted in fig. 4.2.

Throughout this initial brainstorming phase of PBL, there appears to be a stronger emphasis on how these sessions are organised and structured rather than lengthy

discussions of the case content. It shows how when using the 'floating facilitator' approach the team members struggle to monitor the PBL processes especially since they are used to the passive 'lecture-based' approach to learning.

The extracts presented in this chapter show particular instances where one identified strategy was used in context. Since the coding unit comprises only of a single utterance and the extracts show longer excerpts of conversations it may be that different strategies could be identified within one extract. The chosen examples have been picked based on the ability to represent one specific strategy whether they contain utterances that may be attached to a different code or not.

5 | Reporting Phase of PBL: Round 1

This chapter shows the analysis of the reporting phase of problem-based learning, explained in the chapter 3 of this thesis. Figure 5.1 shows the stages of PBL that the reporting phase incorporates. This session occurs immediately following independent research and self-directed learning, it is when the group come together to share their knowledge regarding the learning objectives set out during the brainstorming phase. This is a time for corroborating information, challenging one another, as well as co-teaching to collaborate and reach a greater level of shared understanding. This should lead to a greater team understanding of the problem they have addressed and the ability to apply their new knowledge to answer their original learning objectives.

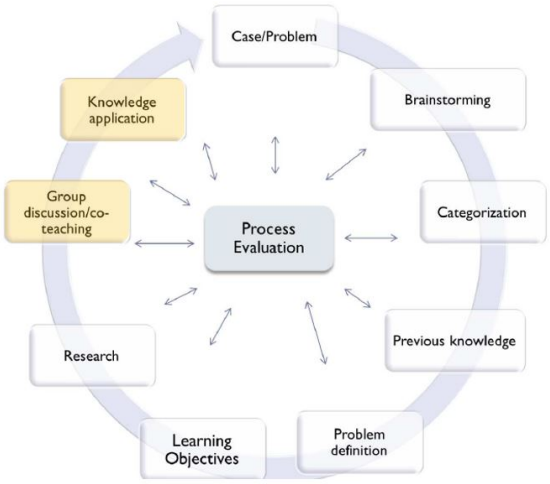


Figure 5.1: Schematic of the PBL cycle as shown to the student teams during Round 1 (2016-2017) of data collection. *(Highlighted are the stages of the cycle that refer to the reporting phase of PBL)*

The following chapter outlines the strategies used by participant teams to further their progress and help organise this final aspect of PBL. The coding frame is summarised and then each strategy is expanded on to give more detail, context and provide examples of each code. Initially discussed is the coding frame which was developed based purely on the transcripts from the first round of data collection. Due to some changes in the

learning environment and administration of the CP306 module (explained in chapter 3) the behaviour of participants in the second round of data collection was quite different thus the analysis of the sessions from 2017-2018 data has been reported separately in chapter 6.

5.1 Coding Frame

The coding frame has been developed using the methods as explained in chapter 3. The transcripts corresponding to the reporting phase of PBL have been analysed systematically to identify strategies used in talk to make progress in the PBL reporting sessions. The reporting phase of PBL is that immediately following independent research of the learning objectives set out during brainstorming. The coding frame has been visualised in fig. 5.2. Each of the strategies will be further elaborated in the sections of this chapter with example extracts of them being used in context (taken from the transcripts). Some of these are common to both the reporting aspect of PBL and the brainstorming phase of PBL, meaning they will have been presented and discussed in detail in chapter 4. These are briefly touched upon but the main emphasis and body of this chapter will be on the description of the strategies unique to this particular phase of the PBL cycle.

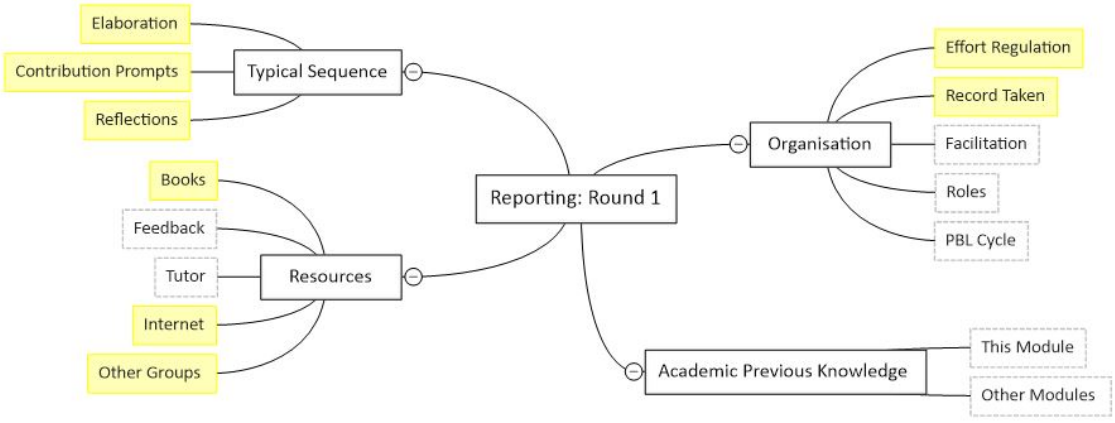


Figure 5.2: Diagram showing the coding framework developed for the reporting phase of PBL using transcripts only from the first round of data collection (2016-2017). This highlights the distinction between concept-driven findings *(box with dashed outline)* and data-driven findings *(yellow shaded box with solid outline)* and how these have been categorised into wider groups *(box with solid outline)*

Once again the strategies have been highlighted as concept-driven findings *(box with*

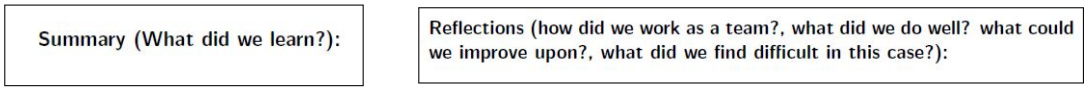
dashed outline) and data-driven findings *(yellow shaded box with solid outline)* as seen in fig. 5.2. This distinction continues throughout the chapter, as with chapter 4. Those strategies which were previously presented as they had been observed in the brainstorming sessions of PBL will be discussed initially before those which are unique to the reporting phase of PBL will be outlined.

5.2 Concept-Driven Findings

This section outlines the strategies which were predicted to occur, these have been derived either from literature or as a result of instructional experience. The way these have been derived is explained in their specific subsections.

5.2.1 Using Language from the PBL Cycle

This was another strategy previously observed in the brainstorming phase of PBL but this time the student teams read aloud the questions asked and included in the summary forms. These are part of the forms where teams would write their learning objectives and can be seen in appendix A.4.1. Although not sophisticated this was a method of starting the sessions with an open invitation to contribute. The question included in the forms asked the group to summarise "what did we learn" (see fig. 5.3a) and this is often the phrase that would be repeated to the team to begin discussions.



(a) (b)

Figure 5.3: Image to show the questions as they appeared in the 'LO and Summary' form for round 1 of data collection (2016-2017). These questions provide prompts for (a) the team to summarise and (b) the team to reflect on their process.

An example can be seen in extract 5.1 where group 1 is discussing the sections of the summary form and what needs to be completed in this session. This was taken from a session when the teams would have been discussing the safety considerations involved in process design. It shows a slightly different instance to when the team would use this question to begin their session.

Extract 5.1: Group 1 - Safety 25:01 - 25:15 (071116D)

```
1    Molly:  what's the next section like
2    Craig:  what the reflections
3    Molly:  so we're putting in the learn what we learned and
4            then
5    Craig:  yeah well we
6    Molly:  oh is the next part just about like how we worked
7    Craig:  how we get there
```

In line 1 Molly asks "what's the next section" and Craig replies in line 2 with "what the reflections". Here Molly is referring to the sections of the summary form and Craig explains how the next section is asking for the team's reflections (the questions seen in fig. 5.3b). Molly continues when she says "so we're putting in the learn what we learned" in line 3, this is how she recognises their current task. The question on the summary form states "what did we learn" so this particular question or concern is what the students associate with the task of reporting back their knowledge and creating a summary. This is further emphasised in line 6 when Molly realises "oh is the next part just about like how we worked" this relates to the prompts for reflections seen in fig. 5.3b. This indicates that although the students might not be aware of particular tasks (by name) and don't necessarily refer to the particular terms seen in the PBL cycle (those highlighted in fig. 5.1) they use these questions to help guide them through the processes.

5.2.2 Attempting Facilitation

This subsection is relating to the strategy of how the team members attempted to facilitate their group's PBL process. In this particular model of PBL, the groups were expected to work autonomously with only brief intervention from a tutor. Barrows (1988) explain the importance of good facilitation, especially when working in PBL for the first time. Therefore, there was some idea that this type of facilitating behaviour would be observed in the data. This was a strategy also observed in the brainstorming sessions of PBL, and was discussed in section 4.2.2 on page 83.

One example of this strategy or behaviour is seen in extract 5.2, this excerpt was taken from a session when group 1 were discussing their research on the design of a heat

exchanger unit. It begins approximately twenty minutes into the PBL session.

Extract 5.2: Group 1 - Heat Exchanger Design 21:26 - 21:52 (070217B)

1	Laura:	shall we do the case then
2	Craig:	so what did we learn
3		(4.0)
4	Craig:	think I kinda learned how to do a heat exchanger
5	Annie:	oh that's handy
6	Craig:	did any of yous lot
7	Sharon:	people said its too much information
8	Linzi:	yeah
9	Sharon:	likes there's so much of it so its kinda important
10		what we're looking at that's maybe your
11	Craig:	ah right

In extract 5.2 Laura begins the conversation asking " shall we do the case then" seen in line 1. Craig reformulates this same idea, in line 2, when he utters "so what did we learn" reciting the questions as seen from the summary form, fig. 5.3a. These questions both show the individuals attempting to facilitate and direct the PBL session. In the given extract it is seen that this is met by a four-second silence from the rest of the PBL group. This is a long time to have no response, recognised since Craig decided to prompt once more (in line 4) by answering his question stating "think I kinda learned how to do it heat exchanger". After this he does receive some response despite it not being extensive it does result in some discussion. A similar phenomenon occurred in the brainstorming sessions, and is seen in extract 4.2 on page 84 where Katie first prompts the PBL team and then answers her question after receiving no response from the other members.

This example emphasises how this behaviour might not be desired by some individuals in the team as it is often met with a lack of response despite its purpose being to encourage discussions.

5.2.3 Assigning Roles

As have been previously explained, in chapter 4, the teams enrolled on the CP306 chemical process module and volunteered to take part in the study were asked to assign a leader

and note-taker for every one of their PBL sessions. Consequently, it was expected that this process would be one strategy used to help the teams manage and direct their PBL sessions. This was first identified when analysing the brainstorming session of PBL and has been presented in section 4.2.3 on page 85.

The particular example chosen from the reporting phase of round 1 is seen in extract 5.3, this shows group 2 around a quarter of the way into the session negotiating who will take the role of note-taker. The team were reporting back on a case looking at the design of a phase separator.

Extract 5.3: Group 2 - Phase Separator Design 14:05 - 14:27 (140217C)

1	Katie:	who's writing then this time
2	Matt:	er I can write if you want
3	Katie:	on you go
4	Matt:	oh who was leader last week
5	Katie:	I don't even know
6	Matt:	I don't think anyone was
7	Oliver:	I've not written notes yet did you say you'd do
8		that
9	Matt:	uhuh
10	Oliver:	did you say you'd write notes
11	Matt:	yeah have you not written the notes
12	Oliver:	nah not yet I'll do this week
13		*((Matt hands the worksheet to Oliver))*

Katie begins the conversation asking in line 1 "who's writing then this time", opening the floor for someone to volunteer. This happens quickly but with some hesitation when Matt responds in line 2 with "er I can write if you want". After Katie states "on you go" in line 3 it seems as if the decision has been made that Matt will be writing for the duration of this session. The talk then turns to who has been leader previously, indicating the possibility that this role also needs to be assigned. However, in line 7 Oliver's admits "I've not written notes yet" and after some confusion, this information leads to Matt reassigning the role to Oliver. The gesture described in line 13 when Matt passes the worksheet (summary form) across to Oliver confirms who is responsible for the note-taking.

This shows one method used to establish who will take on these role responsibilities, extract 5.3 shows how it is dependent on individual members volunteering similar to extract 4.4 on page 87. Other examples show how sometimes the PBL teamwork with a rota developed so that every student will have to take on these positions at least once. This situation has been showcased in extract 4.3 on page 85.

5.2.4 Referring to the Tutor

Similar to the brainstorming phase of PBL there are still instances when the PBL teams orient to the tutor(s) and their comments or conversations to make and strengthen specific points. This might be to establish the possibility of speaking to a tutor as well as referring back to something that the tutor may have said previously. It is often concerning the expectations that the students believe the tutor holds.

Extract 5.4 shows one example when group 1 were discussing a case regarding equipment specification sheets.

Extract 5.4: Group 1 - Equipment Specification Sheets 19:15 - 19:32 (240117B)

1	Annie:	do you think we'll have to do line-do you think
2		we'll have to do line calculations for our in
3		our thing
4	Callum:	don't know actually know how we would
5	Craig:	aye
6	Annie:	they seem like lots of work
7	Linzi:	she's *((the tutor))* not mentioned it
8	Annie:	er
9	Laura:	its cause they're in a case study and she
10		*((the tutor))* was like people should have looked
11		at the cases

In line 1 Annie queries about whether the team will have to complete line calculations in their collaborative project. Here she is relating to the future application of the work they have been completing during the PBL sessions. Callum replies in line 3 admitting he does not know how they would and Annie continues in line 6 stating "they seem like lots of work". Here both team members have positioned this idea as a negative or undesirable

concept. The first instance when the participants refer to the tutor is seen in line 7 when Linzi says “she’s not mentioned it” this is essentially legitimising the negative stance the other team members have taken about this task by suggesting that it is not expected by the tutor. Their tutor is again mentioned in line 9 and 10 when Laura explains “she was like people should have looked at the cases” this is contradicting the team’s initial ideas and suggesting that this would be something they are expected to complete since it has been included in the PBL cases.

The phenomenon which is seen in extract 5.4 is the most recognised type of reference to the tutor when the team are debating and negotiating their efforts or thoughts based on what they believe to be the tutor’s expectations. This is a strategy that the students use to support their own opinions about the task.

5.2.5 Discussing the Written Feedback

Since the students are not working with regular input from a tutor there was an assumption that the feedback they are given on the learning objectives would provide the guidance usually expected from a tutor. The feedback was written purposely to direct students to the intended content relevant to the case so it was believed this would be a valuable and beneficial resource for the team to use during their PBL sessions.

The students’ consideration of their written feedback is unique to the reporting phase of PBL and was not previously identified in the groups’ brainstorming sessions. Regularly in their PBL tutorials, the participants refer back to the feedback that they received on the defined learning objectives from the previous week. They do this in many ways, whether to congratulate themselves on good feedback, complain about too few or bad comments and to discuss how the feedback may have helped to lead the group in a different direction to that which they had planned.

One example of this is shown in extract 5.5. This is a PBL session where group 1 were discussing their research regarding the design of a phase separator.

This extract starts with Sharon suggesting the team “got a lot of smiley faces last week”, this seems to be rather positive and encouraging feedback. This is further emphasised by

Extract 5.5: Group 1 - Phase Separator Design 17:02 - 17:35 (140217E)

```
1  Sharon:  we got a lot of smiley faces last week
2   Linzi:  yay
3   Craig:  a big smiley face
4  Sharon:  I think we got a smiley face on every learning
5           objective its quite good erm so first one find out
6           how to design a phase separator Craig did you find
7           out how to design a phase separator
8   Craig:  me and Annie actually done our research together
9           on sunday
```

Linzi and Craig's responses in line 2 and 3 respectively. This shows one positive evaluation of their work from the previous week but instead of being the students as those who are reflecting on their work, they are relying on the tutor's opinion to give them this validation.

The next extract (5.6) shows again group 1 working on a different case about heat exchanger design. In this excerpt the group are discussing the feedback and why that might be different from what they have now been told by a facilitator.

Extract 5.6 presents a rather different discussion about the feedback they were given. In line 1 Annie begins reading out some information that was given to the students with some guidance and general feedback for the whole class on what should have been covered in the previous weeks of independent learning. She ends with "what were we" in line 4 indicating there was some confusion about what the team were meant to have completed in their independent learning.; asking the group whether the information she has read is true. The team first mention the feedback when Sharon replies in line 5, 6 and 7 initially stating "she didn't say what we wrote was wrong" and their learning objectives were not labelled "wrong" but they do not correspond to the general feedback received today. After this Annie asks "where's the feedback form" in line 10, this is a much more explicit reference to the written feedback they have been given. This shows an alternative instance when the group are having discussions about the tutor's feedback and what this might mean for their research, here the team are using this feedback and general guidance to establish whether their self-directed learning was focused on the intended

Extract 5.6: Group 1 - Heat Exchanger Design 11:30 - 12:07 (070217B)

1	Annie:	wait in your groups you should have discussed what
2		is the general method to design a heat exchanger
3		how is the design of a heat exchanger carried
4		out what are the sets of what were we
5	Sharon:	we were see she didn't say what we wrote was wrong
6		and we had stuff like my section in that case was
7		what kinds of heat exchanger are there and she's
8		not said it was wrong but there she says about
9		design
10	Annie:	because we can where's the feedback form again
11	Sharon:	I have a digital one
12		(5.0)
13	Craig:	in all fairness we did actually have this we just
14		didn't explicitly state this
15	Annie:	mmhm

outcomes.

Both of the examples, extract 5.5 and **??**, show instances where the team exhibit some level of reflection regarding their work and processes. However, it is clear that the students rely heavily on the tutor to give input and that any evaluation does not happen spontaneously.

5.2.6 Activating Academic Previous Knowledge

This section outlines how students demonstrate activation of their prior knowledge and how this is then verbalised for the team to acknowledge and/or agree with. Activation of previous knowledge whether from last week or last year is incredibly important for the success of PBL. The students must be able to relate the cases to domain content studied in the prerequisite modules to properly analyse and understand the case itself. This importance has been documented in Schmidt et al. (2011) and Schmidt (1993). Again the use of academic previous knowledge was a strategy first identified during the students brainstorming sessions when the students were tackling an unfamiliar problem, this was presented and reported in section 4.2.6 on page 93.

In the session for reporting back to the whole PBL group, the teams refer back to both the previous week's work (in this module) as well as bringing up modules they may be currently or have already studied. Examples of these have been shown in extracts 4.9 and 5.8.

The Current Module (CP306)

The first extract (5.7) shows group 1 discussing their work in the PBL module from the previous week. This example was taken from the session where the team are reporting back their research regarding safety considerations in process design.

Extract 5.7: Group 1 - Safety 10:24 - 10:49 (071116D)

1	Annie:	what did we put last week
2	Linzi:	research
3		(5.0)
4	Sharon:	last week was be less vague
5	Laura:	and and it was erm
6	Molly:	improve on being less vague
7	Laura:	was it not something like we know what sites to
8		look at was that last week like it was like
9		engineering toolbox
10	Sharon:	yeah

It starts with Annie asking "what did we put last week", this is regarding the summary form that is required for this reporting phase of PBL. Several suggestions of what was put last week are given by group members in lines 2, 4 and 6.

Often references back to work they have completed in this particular PBL module are focused mainly on the processes and procedure of working rather than about the subject content.

Previous Modules Studied

The second example of the teams activating their prior knowledge is again similar to that seen in chapter 4. The particular example is seen in extract 5.8 and shows an instance where group 1 refers back to a safety module they had previously studied during

a session when the team are reporting back research on safety considerations in process design.

Extract 5.8: Group 1 - Safety 27:37 - 27:51 (071116D)

1	Annie:	mmhm cause all the research it switch between
2		HAZIDs and HAZOPs
3	Sharon:	I think HAZIDs not a huge section
4	Annie:	so its hard to find documentation
5	Sharon:	like HAZOPs a lot
6	Craig:	I think also we've already done tons of HAZOPs
7		like everything we done in safety was a HAZOP
8	Sharon:	yeah
9	Annie:	yeah

In line 1 and 2 Annie starts the conversation talking about her research from the week, this brings up a quick response from Sharon in line 3 before Annie has even fully finished. Craig is the team member who refers back to their previous studies in line 7 citing "everything we done in safety was a HAZOP". It is known that by reaching this point in their degree the participants will have completed a module on safety in chemical engineering and this is what Craig is relating to in his utterance. This is quite vague but highlights to the other group members why they might be more focused on the HAZOP aspect as this is a familiar topic that they have covered in detail for a different module.

It is useful to note here that there are instances in the reporting phase of PBL where the teams do exhibit and verbalise the activation of their academic knowledge. Much like the participants did when first approaching the brainstorming aspect of PBL however it is quite different in execution, this time when the students refer to this particular module they are focused on their process in the previous sessions rather than the content. Regarding whether the teams show that they make connections to their own previous learning experience are of lower priority during this aspect of PBL since the teams will have conducted some independent research so should be more familiar with the problem at hand.

5.3 Data-Driven Findings

5.3.1 Effort Regulation in Talk

Noticed in both the brainstorming and reporting phases of PBL was the student's awareness for the effort that may be required for the particular problem or the effort and workload that they have already completed.

The example is shown here, in extract 5.9, gives one occasion when group 2 are discussing the effort that they have given to the case which they should have been working on throughout the previous week. This was a case covering material and energy balances.

Extract 5.9: Group 2 - Material and Energy Balances 5:59 - 6:46 (161116A)

```
1   Oliver:  shit did yous do much for this
2     Ryan:  nah
3   Oliver:  no
4     Ryan:  nah
5            (unclear speech)
6     Ryan:  I literally just got one picture up and then just
7            wrote it down
8   Oliver:  yeah I know I'm just gonna get a screenshot of it
9            its like what's the point of me re-writing it its
10           just gonna say the same stuff if I take a
11           picture anyway
```

This extract has been taken from the very beginning of a session where the team would be discussing their research on material and energy balances. This conversation occurred with only half of the team members in the room. In line 1 Oliver first asks "shit did yous do much for this", the expletive and his question imply that maybe Oliver has not completed enough work for this particular case and he is worried that this is unsatisfactory. The reply from Ryan in line 2 and 4 when he says 'nah' legitimises Oliver's implied lack of effort because this has become the norm for the whole group and not only one member. This conversation continues and both Ryan and Oliver explain what they have done and

why this should be acceptable.

The main difference between how this regulation of effort is observed in the reporting phase is how they are often explaining why they might not have completed something whereas in the brainstorming phase of PBL the teams are often negotiating the level of effort they believe they should put in for the upcoming week.

5.3.2 Record Taken (Making Notes)

In this round of data collection, the teams were asked to complete a learning outcome and summary form (see appendix A.4.1). They had to submit a written record of their learning objectives for the brainstorming phase of PBL and a summary of their research during the reporting phase of PBL. Therefore when this is identified from the data corresponding to the reporting phase this strategy relates to the summary the team must write and submit for feedback.

An example is seen in extract 5.10 shows group 2 discussing their independent learning regarding a case focused on fluid handling equipment.

Extract 5.10: Group 2 - Fluid Handling Equipment 20:24 - 21:24 (310117G)

1	Katie:	basically just like rules of thumbs that they use
2		I've got the link for them if like for when
3		they'll be and that's it from me then
4		(3.0)
5	Katie:	have you written enough *((to Ryan))*
6	Ryan:	yeah
7	Katie:	Yasmin is also on that learning outcome
8	Yasmin:	erm so the things that required for hydraulic
		calculations

The extract begins with Katie, in lines 1 and 2, reporting back to the team with her research. She ends in line 3 stating "that's it from me then" this is opening the floor for someone else to take over and discuss their contribution. The three-second silence seen in line 4 demonstrates the reluctance of other team members to take over and explain what they had learnt in the week. They appear to be waiting for someone to make a decision

or tell them who should be next. This is when Katie begins again in line 5 asking Ryan specifically “have you written enough” from this it could be assumed that he is currently undertaking the role of the note-taker and that Katie is checking that he has added her information to the summary form. Here we then see that Katie names another team member who then does begin to explain her research to the PBL group. Prompts such as this one are very unique which are only exhibited in the reporting phase of PBL, these have been presented and analysed in detail in section 5.3.6 on page 131.

The idea that students do discuss what should or shouldn’t be included in the summary emphasises their reliance on the input from a tutor since the summary forms will be what the module leader will give them feedback on. The meticulousness they demonstrate is problematic because it signifies how they are aiming for a perfect answer to make sure their notes will be what the tutor wants to see. They are focused only on the outcome when it is the process which is most important to thrive in problem-based learning.

It must also be acknowledged that when the team are concerned about what has been written down, this indicates that the summary form is a common document which the team are all responsible for. Whereas if the written record is not discussed it might only be one student making decisions about what should be included.

5.3.3 Reference to Books

Referring back to chapter 4 the analysis found that the participating student teams were rarely making use of resources outwith the module remit during their brainstorm. The sources of information they would call upon regularly included mainly the case material and conversations with tutors or course leader with some mention of software tools. This appeared and was interpreted to suggest that the teams were not making use of the variety of resources as would be expected in a PBL learning environment. However, during the analysis of the reporting phase of PBL once the teams had executed their research and came together to discuss the new knowledge it was clear that the use of different resources was much more apparent within this particular session. The teams still make use of those same resources from the module but there were many more references to other sources of information, including the use of books.

One key strategy identified in this analysis was how the teams report their use of books, specifically textbooks (most of which were recommended reading for the module). The reference to textbooks is sometimes observed as a vague reference to what should have been or was looked into during an individual's research rather than a way of validating the new knowledge and strengthening an opinion.

An example is displayed in extract 5.11. This extract shows group 1 when they are discussing a case which required the design of a heat exchanger.

Extract 5.11: Group 1 - Heat Exchanger Design 12.08 - 14:18 (070217B)

1	Craig:	we obviously need to know the general heat
2		exchanger cause we designed it like how
3	Annie:	didn't design it properly though
4	Linzi:	we didn't really design it though
5	Craig:	yeah well you know what I mean
6		((laughter))
7	Craig:	and then like design considerations
8	Annie:	but for that we should have gone and looked at
9	Craig:	we tried that I looked at that Sinnott
10		thing and it the book didn't really help us that
11		much they have like forty pages on heat exchangers
12	Annie:	yeah
13	Craig:	seemed a bit excessive

In this extract, there is some confusion about whether they have managed to complete the heat exchanger design. Craig makes the first comment about this in line 2 when he says "cause we designed it". This comes up against some critique when Annie states "didn't design it properly" and Linzi repeats this same sentiment in line 3. The reference to books happens in line 8 when Annie suggests that they "should have gone and looked at the book" this demonstrates how sometimes students may give a loose explanation of what "the book" might actually be. A clearer link is seen by Craig in line 10 when he mentions "that Sinnott thing" by including the author of the recommended reading (Sinnott & Towler, 2009) he publicly acknowledged the specific book Annie was referring to. Craig then elaborates on this in lines 11 and 12 giving a strong opinion on how

unhelpful this textbook was, his justification being that there are too many pages and this is “a bit excessive” (line 14).

There are also several instances when the teams refer to the textbooks specifically by the author which suggests they are taking some initiative and distinctly directing their research process and shows transparency by the individual because the group could cross-reference to check it was the true source of information. Often they refer to books or textbooks such as these to validate their decisions or strengthen information which they have relayed to the team. An example of this has been presented in extract 5.12. This extract shows a time when group 2 were discussing their own attempt at completing the calculations related to the design of a heat exchanger.

Extract 5.12: Group 2 - Heat Exchanger Design 18:49 - 20:12 (070217E)

```
1  Katie:  what did you use for like the length of the tubes
2   Matt:  you assume its two metres
3  Katie:  yeah so
4   Matt:  from Sinnott and Towler
5  Katie:  erm everyone all other groups are doing it much
6          longer
7   Matt:  yeah
8  Katie:  so I've did it longer
9   Matt:  see I've did it because er you have to pick a
10         reasonable diameter and for it to be cheap cost for
11         steel is between 16 and 25 millimetres diameter for
12         your tubes that means that your because its high
13         steam as well like high temperature we'd have
14         thickness quite thick so it has to be either 2.8
15         or 3.2 I picked 2.8 cause its cheaper again
16 Katie:  yeah
17  Matt:  and then by using that it gives you on Sinnott and
18         Towler a table and then it gives you like six foot
19         which is like roughly two metres
20 Katie:  mmhm
21  Josh:  1.8 isn't it that's what I used
22 Katie:  I used like six metres
```

Extract 5.12 starts with Katie asking in line 1 “what did you use for like the length of the tubes” this is an assumption which the students need to decide for themselves so might have been different for each team member. Matt’s reply in line 2 appears quite final “you assume its two metres” that this is the correct decision for moving forward, the continuation in line 4 explains his reason for this since it is “from Sinnott and Towler” so it could not possibly be wrong. Here Matt is explicitly referencing the source of his new information making it obvious to the group how he came to the conclusion he has and supports his decision since it is a supreme knowledge source. Katie responds to Matt in line 5 and 6 suggesting she did not use his proposed technique because she had conflicting knowledge from the other teams who were taking the CP306 class. The mention of friends or other class members was another method of invoking an external source of information to back up a point being made and is further discussed in section 5.3.5 of this chapter.

This particular strategy shows more promise for the students in terms of their individual self-regulation. It might be that now the learners have had time to conduct their research this is now when they make use of a variety of sources of information. Whereas when the groups are just starting the PBL process and working with an unfamiliar problem case the participants work only with what they already know and do not begin looking for further knowledge sources.

5.3.4 Use of the Internet

Another popular source of information is the internet, whether through mentioning web pages or the infamous google search the students often default to this as an efficient research technique. A parallel between this code and the use of books has been observed by how some students resort to vague and ambiguous explanations of where they found information (e.g. “I googled” line 3 in extract 5.13) and others who explicitly state the direct source (e.g. “HSE website” line 3 in extract 5.14).

The first excerpt which illustrates how students refer to using the internet as a source of information is seen in extract 5.13. This example has been taken from a session where group 2 were discussing fluid handling equipment; the details, design and selection of

them.

Extract 5.13: Group 2 - Fluid Handling Equipment 29:24 - 30:26 (310117G)

```
1   Ryan:  er LO3 Josh
2   Matt:  Josh
3   Josh:  its LO3 I googled erm basic engineering design
4          report got nothing so I just had like a kinda a
5          look at different reports erm just kinda assumed
6          normal things so erm design reports are obviously
7          done to introduce and document engineers designs
8          ((Josh continues to elaborate ...))
9   Josh:  so kind of what would a basic engineering design
10         report be like at preliminary stage just to
11         communicate the initial design to these parties erm
12         but I found nothing to support that its just
13 Katie:  you just made it up
14  Josh:  my own speculation yeah
```

In line 1 we see that Ryan asks Josh to contribute with his ideas about LO3 (learning objective three). Josh leads into his content with "I googled erm basic engineering design report got nothing" seen in line 3 and 4. This indicates that his google search was not helpful despite his referring to a specific site here he is only discussing his process of research and not outlining the sources behind his information. Josh then states "just had like a kinda a look at different reports" in lines 4 and 5. This might have been from the Google search but it is ambiguous; by mentioning different reports this would not help the team should they wish to look up the same thing in the future. For the remainder of time while Josh is talking he is elaborating on these 'reports' until he concludes his thoughts in lines 9-11 giving a summary and answering the original learning objective he was assigned. Interestingly in line 12, Josh gives a disclaimer about this information when he says "I found nothing to support that", this shows that he is aware that content does need to be back up with sources. Katie replies in line 13 accusing Josh "you just made it up" which he then agrees with in line 14 "my own speculation yeah".

This example shows one instance where a team member gives vague reference to using

the internet, and that the result was a google search which did not bring up the necessary information. It does, however, give some demonstration that the students are searching more widely for the information needed to fill the knowledge gap previously identified. Josh also shows his understanding that all content needs to be referenced, this a key skill when working in a group and will be invaluable in his further studies.

The next example has been taken from group 1 when they were researching phase separator design. Extract 5.14 shows when the group member references to a specific website when they are relaying the content to the rest of the PBL team.

Extract 5.14: Group 1 - Phase Separator Design 22:58 - 23:21 (140217E)

1	Sharon:	Laura did you get anything on safety
2	Laura:	what was it that you got
3	Sharon:	it was HSE website was the best one I found
4		a few different ones but it basically just had
5		like all the control measures
6	Laura:	yeah just like emergency stuff like that
7	Sharon:	what I found was like stuff like if corrosion
8		happened in the vessel what coatings you would
9		use and stuff like that
10	Laura:	I'll post mine in the group chat
11	Sharon:	yeah

This begins in much the same way as extract 5.13 in line 1 when Sharon invites Laura to start the conversation with what she learnt in the week. However, Laura answers this, in line 2, by asking Sharon to elaborate on the same topic. In line 3 Sharon replies but she prefaces her response by saying "it was the HSE website" this highlights the actual name of her source. This gives the rest of the group the knowledge themselves and means the team would know where to look if they needed to look at this topic in the future.

This example shows a more transparent and explicit way of mentioning the resources that team members have made use of in their independent learning. This is a valuable skill as the teams will need to use these sources when they come to conduct and organise group projects in the future.

5.3.5 Other Groups

As well as using materials or references as a knowledge source, there are some references to people too including other friends or PBL groups working in the same class. This is similar to when the students discuss conversations they have had with their tutor (seen in section 5.2.4) but referring to other students in their class.

Earlier in extract 5.12 the group is debating what would be the right assumption to make when conducting calculations to design a heat exchanger, and as was written in section 5.3.3 Matt refers to the recommended reading (see line 4) to give evidence for his decision. It is seen in this extract that Katie makes use of other knowledge sources, by mentioning to the team that "all other groups are doing it much longer" this suggests that she has spoken to other teams or students in the class and they have given her conflicting advice to Matt's. In this case, Katie has used the knowledge that the other students have given to her regarding the content of the problem and how it can be solved.

There are other times when the teams discuss other groups when focused more on their process in the PBL sessions rather than the subject content and details. One example is seen in extract 5.15 shows how group 1 is discussing the PBL process and how they should conduct their research.

Extract 5.15: Group 1 - Heat Exchanger Design 19:52 - 20:13 (070217B)

1	Linzi:	I don't know she just said carry out calculations
2		and produce a design for a heat exchanger everyone
3		must do it
4	Craig:	think its easier as a group
5	Laura:	produce a design
6	Linzi:	yeah
7	Sharon:	yeah people say do it individually now I'd rather
8		do that as a group cause its a group marked class
9	Laura:	yeah
10	Linzi:	yeah
11	Molly:	I think a lot of the groups done it individually
12		think that's what she told them they were to do

This extract starts with Linzi stating what their tutor had asked “she just said carry out calculations and produce a design” in line 1, and that “everyone must do it”. This begins the negotiation of whether this task must be completed as a group working collaboratively or by each member individually. The intention is purely that the students each gain the knowledge and understanding of how to design a heat exchanger and often if completed “as a group” there may be some team members who will not engage. In line 7 Sharon says “people say individually” this is ambiguous and could be referring to the tutors of the class or other students also taking part in the class. Eventually, Molly makes a more direct point in line 11 saying “I think a lot of the groups done it individually” which might persuade the rest of the team to work in the same way that these supposed other groups have done.

The second example is quite different to the first since it appears to be more speculation of what Molly thinks the other groups might be doing and is in relation to how the team works rather than the subject-specific content. This section just shows how different PBL groups are oriented to in talk and they are assumed to be another knowledge source that can help the team (much like the module tutors).

5.3.6 Typical Sequences

This category is one of the most fascinating, this suggests how the sessions are sequenced and the significance of how speakers take turns. It has been proposed and explained to the students that in these sessions individual team members are expected to report back to the group and conduct co-teaching of the content that they were researching in the preceding week. It was observed that the way which the groups managed this aspect of the PBL tutorial was by naming individuals to come forward and relay the research that had been previously assigned to them. This process led to some instances where the teams each took turns to lecture the group on the content they have gathered over the course of the week. The following subsections discussion the prompts for students to come forward with what they have learnt and then the elaboration which occurs following these prompts.

Contribution Prompts

A noticeable occurrence in this consolidation period was how often participants were named and asked to give a contribution to the group PBL tutorial. Many students would name team members to come forward with their independent research conducted during the self-directed study, this type of invitation is rarely seen in their initial planning stages where the learners are unfamiliar with the problem content. In their brainstorming, any questions asked would usually be open invitations for all team members to answer whereas during this reporting phase of PBL there appears to be some expectation that each team member will take their turn to report their research. There may have been less expectation for each student to perform and contribute to the brainstorming session and during early conversations when all students are 'novice' with the case at hand.

Extract 5.16 shows an example of these prompts in practice. The excerpt has been taken from a session where group 1 were discussing their research on safety concepts in chemical process design.

Extract 5.16: Group 1 - Safety 18:26.8 - 22:50.4 (071116D)

1	Craig:	how did you do *((to Linzi))* are you finished
2		*((to Sharon))*
3	Sharon:	that was it I think
4	Craig:	how did you do Linzi
5	Linzi:	I just learnt what is a HAZID so its a qualitative
6		technique for early identification of potential
7		hazards affecting people environment assessts
8		and reputation
9		*((laughter))*
10		(12.0)
11	Craig:	so basically identifying it before you've built
12	Linzi:	yeah
13	Craig:	before you've actually built the process

In line 1 and 4, Craig picks out Linzi as the next speaker to present her work. This is done in line 1 by directing his question to her "how did you do" and then more explicitly in line 4 using her name aloud "how did you do Linzi". By using the specific

invitation for a speaker it forces the student to take the floor, which might be less likely had it been an open question to the whole team. From the analysis of the brainstorming session, it was identified that once learning objectives had been formulated the teams would divide these between members so that everyone has some unique responsibility. The behaviour described shows (through their discourse) how the group hold each team member accountable for their individual contribution. There is an expectation that you should have information to relay back to the team. This method of prompting specific speakers to come forward does not always happen by calling them out by name but also by the mention of a specific learning outcome or issue that was raised and allocated to a team member during their previous PBL session. There are several instances in the data corpus where groups used both these techniques.

An example of contribution prompts using the specific topic can be seen in extract 5.17. This extract was taken from a session where group 2 were discussing safety concerns in chemical process design.

The prompt for contribution is in line 1 of extract 5.17 when Hannah says “learning outcome one”. This is a less direct and explicit manner of calling someone forward instead of using a name by using the content its less like putting someone on the spot; it could be deemed more polite. There is also an argument that naming people in questions could help engage the quieter characters by giving them space and time to join the discussion rather than having to compete with the more dominant or able team members.

Elaboration

Contribution prompts would then often lead to long elaborations where one team member would read aloud some or all of the research they had collected over the week. This almost positions them as the expert with all other team members being taught by them at this point in the session. Extract 5.17 shows one particular instance from the data which was taken from the reporting session where group 2 were discussing the safety case.

In line 1 Hannah starts by asking “so learning outcome one”, this is asking the team member or members who were assigned this as their research to report back to the whole PBL team. This leads to some confusion between Yasmin and Oliver who were the two

Extract 5.17: Group 2 - Safety 1:18 - 5:23 (071116C)

Hannah: erm so learning outcome one
Oliver: me and yasmin do you wanna say one about through the hazid
Yasmin: yeah
Oliver: yeah
Yasmin: er I'll start this
Oliver: pardon
Yasmin: sorry so I will start this or
Oliver: oh yeah you start answering go on
Yasmin: ok so I found that er for instance there are two types of hazids cause there is a chemical reaction and operational hazards and for er operational operational hazards we have like erm we have like areas of flammable atmosphere er this is er when we have a bit in secondary reforming so then er we have er sorry we have air and then I think er there is like possible leaking for the possibly possibly because er our reaction that I need there is possibility that er reaction that occur in secondary reforming has some erm areas that are erm what I say are flammable atmosphere erm and we have like sources of ignition er so I think er possibly for each steps we have like precaution steps that we need to erm we need to we have like precaution steps er for the each parts for the safety of the company so that's all
Oliver: ok erm I did like just the hazards like I started for that the conventional process but then I realised that I should have done it for a general thing so I just did it for like general hazards *((Oliver continues to elaborate))*

members responsible for this specific learning objective about who should go first. This is clear when we see the exchange in lines 6 through to 9. Ultimately Yasmin begins and her elaboration continues from line 10 for some time without interruption.

This only finishes when Yasmin herself says "so that's all" in line 27. After this Oliver then begins and he continues to talk through his findings for around three minutes (this has not all been included in the extract so that it is brief and succinct). Throughout Oliver's elaboration, there is no point when any other team members show engagement in terms of an agreement, questions for clarification or challenging the information and its sources. This suggests that while one member is speaking the rest of the team does not appear to be actively listening or processing the content. In the transcripts, it is often only the note-taker who indicate that they are listening (from their talk) since they have to summarise every team members content for the 'LO and summary form' (see appendix A.4.1).

While it is positive to see that the students have conducted thorough and detailed research, it would be more beneficial for the student's learning to have more critical discussions about the content. There is a lack of active participation in the session unless you happen to be the one person reading out to the rest of the PBL group. This becomes problematic when the teams come to work on their group project when this knowledge is necessary and yet they had not previously learnt from one another meaning that this process and research would need to be repeated.

Reflections on the Group Process

Another point in the sequence of sessions happened to be when the students would reflect on their group process and how they have worked. This would regularly happen towards the end of the reporting phase of PBL, since it was included as part of their summary form (see appendix A.4.1). The particularly questions which might be used can be seen in fig. 5.3b.

Extract 5.18 presents an interesting excerpt of conversation towards the end of a PBL session where group 2 had been discussing chemical process design safety.

Extract 5.18: Group 2 - Safety 45:45 - 46:25 (071116C)

1	Katie:	have you written some reflections do you want some
2		ideas
3	Josh:	what you thinking
4	Katie:	we could say that we changed out learning outcomes
5		after feedback from Esther *((the tutor))*
6	Josh:	mmhm
7	Matt:	made use of feedback well
8	Katie:	yeah

The extract starts in line 1 when Katie first asks “have you written some reflections” this looks positive since the groups need to reflect on their process as a team, what they have achieved that week and also what they might want to improve upon. The idea that Katie is prompting the group to address this is promising. However she continues to ask “do you want some ideas”, this would now imply that she would just make up or think of superficial ‘reflections’ rather than it being considered by the team as a whole. Josh replies asking “what you thinking” in line 3, indicating that it is he who would be writing them down. Katie then gives her proposal suggesting “we could say that we changed our learning outcomes after feedback from Esther” in line 4, she has now made it clear that she is talking on behalf of the PBL team since she has used the ‘we’ pronoun referring to the collective team. Josh’s utterance in line 6 suggests some agreement and this is further expressed when Matt reformulates the idea in line 7 stating “made use of feedback well”. Here there are three of the team members who are taking part in the decision process for what the team should write for their reflections. Unfortunately, this is less than half of the PBL group so the other group members thoughts and feelings are currently being ignored or at least not actively sought out. It could also be said that this instance does not show any real reflections especially not as a team it is almost as if Katie has just decided how the group worked and the rest of the team go along with this.

There are fewer instances where the conversation does suggest the group make reflections on their collaborative working. Extract 5.19 shows group 1 discussing how they have worked on a case focused on heat exchanger design, this is after an hour of reporting back their previous week’s research.

Extract 5.19: Group 1 - Heat Exchanger Design 1:00:46 - 1:01:24 (070217B)

1	Linzi:	how did we work as a team then
2	Craig:	I'd say quite well we all sat and done
3		the heat exchanger and failed together
4	Laura:	Linzi didn't fail we got it started
5	Annie:	well actually yeah Linzi and Laura worked on the
6		heat exchanger I tried to get the aspen simulation
7		going which group were you in Molly and Sharon I
8		specifically remember Craig doing not very much
9	Craig:	I was there I was there for team spirit
10	Molly:	I tried the calculations
11	Craig:	I also helped you with the aspen
12	Annie:	no you didn't aspen wasn't working
13	Craig:	oh I helped you when it wouldn't stop working

In line 1 Linzi first asks "how did we work as a team then" this prompts the team to think about how they thought the team has worked, this question happened to be one which was included in the summary form see fig. 5.3b. Craig starts very positive saying "I'd say quite well we all sat and done the heat exchanger and failed together" here he implies that despite the team not being able to complete the task or supposedly 'failing' they still worked well because the group were working collaboratively. Laura contradicts Craig in line 4 when she states "Linzi didn't fail we got it started" this now explains that they had not failed but they might not have completed the task fully. By specifically naming Linzi this places the achievement or effort only with her rather than the whole team. This is even further emphasised when Annie joins in line 5 where she gives her thoughts on the situation, in this utterance she runs through the contributions of all the group members. Annie ends in line 7 & 8 stating "I specifically remember Craig doing not very much" this results in Craig trying to justify and explain his role in the team's work. Despite never explicitly stating that they were reflecting this conversation shows clearly that the team are evaluating their group processes and each individuals contribution. This is incredibly important since the group will be working together for a full year they need to develop and improve their processes. By explaining to Craig here that it appeared he had not done enough this week, he is aware and can change this in the future.

It is promising to observe this type of reflection and evaluation of the processes which the PBL groups will work through. This behaviour is necessary for the students to truly take responsibility for their learning by understanding what might or might not have worked well then the team can adapt and develop together. The difference between extracts 5.18 and 5.19 could be attributed to the time when they occurred, the first being in November during the first semester working with PBL and the second in February when the PBL teams have had some time to settle into a working routine. At this point, they will be much more familiar with one another and with the PBL processes. Data would need to be examined and further analysed to make comparisons and give a conclusive answer to whether this is the case.

5.4 Summary

This chapter has described the strategies which were identified from the first round of data collection for the reporting phase of PBL. This is after students have completed their independent research and must report their knowledge to the rest of the PBL group. Examples of these strategies have been presented and reviewed throughout this chapter with a specific focus on those which were both data-driven and unique to the reporting PBL sessions. These strategies have been summarised in table 5.1 (corresponds to the codes in fig. 5.2 on page 110). This table shows the broader categories that were developed during the analysis as well as highlighting (as yellow shaded cells) the particular strategies that are unique to the reporting PBL sessions.

Of these strategies there are few which are similar to those presented in chapter 4 especially the way that the students organise their sessions and the teams again discuss their previously studied classes which may be relevant to the case at hand. The most significantly different finding is the variety and time they spend discussing resources they have or plan to use. This could have been expected because the reporting session occurs once the teams have had time to go away, find the information to answer their learning objectives from the previous week to fill the gap in their knowledge. So they are more likely to have found and looked at more different sources of information, this is exactly what was observed in the data itself.

Table 5.1: Summary of the strategies identified from the analysis of the Round 1 reporting phase data and how these are clustered to form larger categories.

Organisation	**Resources**	**Academic Previous Knowledge**	**Typical Sequence**
Effort Regulation	Tutor	This Module (CP306)	Contributions Prompts
Roles	Books	Previous Modules	Elaboration
Facilitation	Internet		Reflections
Record Taken	Feedback		
	Other Groups		

An important issue that emerged from the analysis of the data was how the students sequence this PBL session, the teams tend to work through the learning objectives established in their previous session and ask the team member assigned this content to report back to the group. This was seen from the concept of contribution prompts followed by elaborations, as presented in section 5.3.6. It was often one member (possibly the person assigned leader that day) who gave these prompts then each member would take their turn relaying their learning to the whole group. By the nature of this process, the team members are only actively taking part when they are talking, the content and knowledge is not being fully processed by all the team members. This is a concern about using a problem-based learning pedagogy for engineering education since the subject has a hierarchical structure and when the students take this approach they will be gaining only fragmented knowledge.

The next chapter (6) goes on to discuss how some changes to the module administration had an effect on the strategies identified in talk for the participants from round 2 of data collection.

6 | Reporting Phase of PBL: Round 2

This chapter follows on from the previous chapter 5, and contains the analysis of the reporting phase of problem-based learning from the second round of data collection. This session is for corroborating information, challenging one another, as well as co-teaching to collaborate and reach a greater level of shared understanding. This chapter outlines the strategies used by participant teams from the second round of data collection.

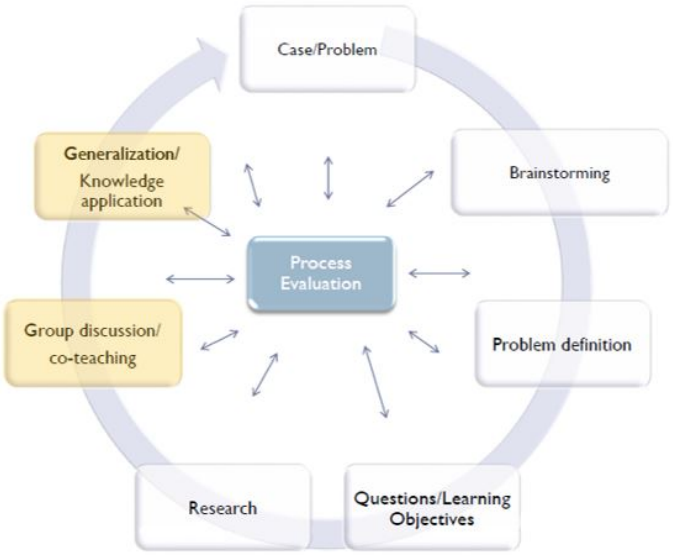


Figure 6.1: Schematic of the PBL cycle as shown to the student teams during Round 2 (2017-2018) of data collection. *(Highlighted are the stages of the cycle that refer to the reporting phase of PBL)*

The coding frame is summarised and then each strategy is expanded on to give more detail, context and provide examples of each code. Initially discussed is the coding frame which was developed based purely on the transcripts from the second round of data collection.

The reporting phase of PBL was analysed separately for the two rounds of data collection due to changes in the module administration between the first and second round of data collection. In the second round of data collection, the PBL aspect of the class was

conducted only during semester one, but the students were expected to still complete a total of 15 problem cases. This led to a rather hectic schedule with the PBL teams having to complete two cases during every week of the semester. The teams were also expected to produce summary notes to be submitted a couple of days following the reporting session for each case. These summary notes were graded and added towards the assessment portfolio for the class which would make up their final grades. More details of the learning setting for each year of data collection is outlined in chapter 3.

6.1 Coding Frame

The analysis included in this chapter has been conducted using the methods described in chapter 3 and is solely focused on the development of the coding frame used to describe the data. As explained the analysis in this chapter is based on the reporting phase of PBL during the second round of data collection. The coding frame is the result of this analysis. The final coding frame is visualised in fig. 6.2. Once again the strategies have been highlighted as concept-driven findings *(box with dashed outline)* and data-driven findings *(yellow shaded box with solid outline)* as seen in fig. 6.2.

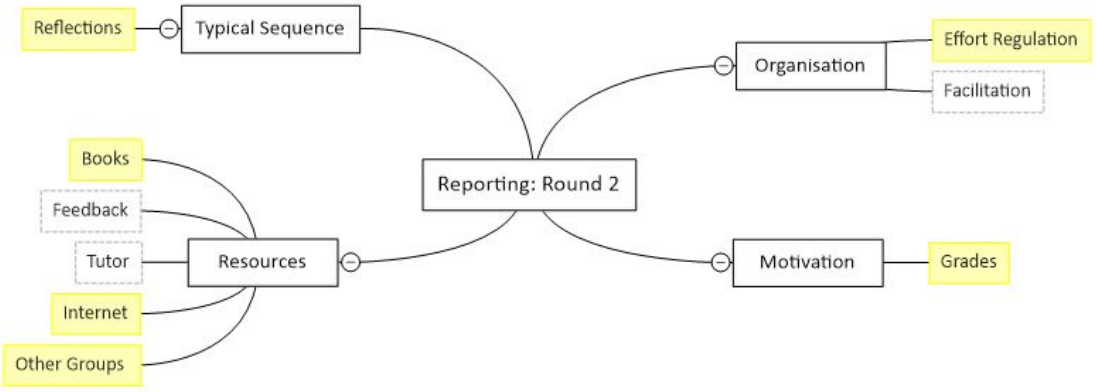


Figure 6.2: Diagram showing the coding framework developed for the reporting phase of PBL using transcripts only from the second round of data collection (2017-2018). This highlights the distinction between concept-driven findings *(box with dashed outline)* and data-driven findings *(yellow shaded box with solid outline)* and how these have been categorised into wider groups *(box with solid outline)*.

Figure 6.2 shows the strategies which were observed in the reporting phase of PBL for group 3 and 4. Some of these codes have previously been seen in fig. 4.2 on page 81 and

fig. 5.2 on page 110. This chapter will discuss how these were observed during this round of data collection and explain in detail the strategies which are unique for this round of data collection.

The analysis for the second round of data collection was conducted with the idea that the behaviour of students might have been affected due to changes in the module organisation. The strategies identified from this corpus of transcripts are outlined with representative example extracts in sections 6.2 and 6.3 which correspond to the concept-driven and data-driven findings respectively. A detailed discussion of how and why these might differ to those presented in chapter 5 is seen in chapter 7.

6.2 Concept-Driven Findings

This section, similar to sections 4.2 and 5.2, contains concept-driven findings; strategies which were thought to occur. These were informed by previous literature as well as practical experience facilitating problem-based learning. The reason why these findings were predefined may have already been discussed in a previous chapter, in which case the corresponding section will be referenced. These findings have been visualised and highlighted in fig. 6.2 as those with a dashed outline. Each subsection will describe and give examples of these strategies in use during the student's PBL sessions.

6.2.1 Attempting Facilitation

The first strategy being discussed has been consistently observed in all analyses. This is how the students make attempts to facilitate their PBL sessions. This was expected due to the fact that the students were having to self-manage the majority of the time during their PBL sessions. It was expected that some team members might have assumed this responsibility themselves since the module uses a 'floating facilitator' approach. Facilitation such as this includes when a team member is aiming to start discussions, make decisions or get the group back on track. This section presents two example excerpts taken from the transcripts which are representative of how the students from this cohort would facilitate the PBL process.

Extract 6.1 gives an example of when this was observed in the second round of data collection. It has been taken from the beginning of a session when group 4 were reporting back their findings on process design basics. This shows how one team member made the suggestion

Extract 6.1: Group 4 - Process Design Basics 04:20 - 04:38 (021017AUD1)

1	Emily:	case two just needs put together I think
2	Nick:	yeah I can't I don't know how we're gonna put
3		the calculations in it I get
4	Adam:	he hasn't asked for that
5	Emily:	I think we're just gonna take can we not just
6		take photos and
7	Nick:	we need to decide cause I think I've actually
8		got different values to you *((to Adam))*
9	Adam:	do you
10	Nick:	cause you said that R101 was bad
11	Adam:	yeah
12	Nick:	right I'm saying it's fine
13	Adam:	oh

Extract 6.1 begins with Emily in line with the sentiment that "case two just needs put together" as an opening statement. Nick responds to her in line 2 and 3 with an issue that might complicate her original thought since he says "I don't know how we're gonna put the calculations in". Here Nick insinuates that there are barriers which need to be addressed before the team could put the 'case together' like Emily first proposed. In reply to this Adam refers to someone unknown when he says "he hasn't asked for that" in line 4 presumably this is another team member who is working on the case at hand. Emily gives her solution in line 5 and 6 asking "can we not just take photos" recommending the team take photographs of their working for specific calculations to be included in the summary submission. In line 7 Nick instructs the group that they "need to decide' this shows he is prompting the team into the decision making process. This is quite a subtle way to approach the facilitation specifically because he uses the 'we' pronoun he is showing a shared responsibility for the decision. Nick also continues his utterance in line 8 talking to Adam he says "I've actually got different values to you" leading to a slightly different

discussion about the calculation results.

The second example of team members facilitating the problem-based learning session has been taken from a session when group 3 were starting their discussion. In extract 6.2 the students are deliberating on which case the team should focus on for this PBL session. The session itself was dedicated for case one which initially introduced process design but the team are also working on another case (number 2) during this week.

Extract 6.2: Group 3 - Process Design Basics 7:36 - 8:42 (021017W2B)

1	Eva:	was it just case 1 we're speaking about today
2	Richard:	case 1
3	Eva:	we've already finished case 1 so should we
4		speak about case 2
5	Jamal:	yeah I'm up for that
6	Richard:	if you want can't what was case 1 again
7	Eva:	case 1 was the
8	Richard:	oh the presentation
9	Jamal:	apparently a lot a lot of the marks for that
10		one is about the content of the presentation
11	Richard:	yeah

Extract 6.2 begins with Eva in line 1 she starts the discussion of the case when asking "was it just case 1 we're speaking about today". Line 2 shows Richard's agreement and is followed up by Eva who demonstrates further facilitation of the PBL process by suggesting "should we speak about case 2". Again she uses 'we' to establish shared responsibility, similar to Nick in line 7 of extract 6.1. The replies that she receives are all positive and agree with her suggestion, see Jamal in line 5 and Richard in line 6. The conversation has now begun regarding case one and continues for the remainder of the extract.

Interestingly this is also the first extract that has included a reference to the students' grades or "marks", seen in Jamal's utterance from line 9. This strategy will be further described in section 6.3.6.

This is quite different to the examples seen in extract 4.2 on page 84 and extract 5.2 on page 113. Since in those the team members were more reluctant and resistant to

facilitation in the particular context. Whereas the examples seen in extracts 6.1 and 6.2 show more positive and agreeable reactions to these prompts. It appears as though for this context the facilitation was less noticeable as taking authority compared to the previous situations. These ideas will be further explored in chapter 7.

6.2.2 Referring to the Tutor

This section relates to the times when students refer to their tutor(s) this could be demonstrators or the course leader. Often when the participants mention their tutor it is relating to either previous conversations or the expectations that a tutor may hold. This is a strategy which has been present in all analyses, examples can be seen in section 4.2.4 on page 88 and section 5.2.4 on page 115.

The example from this data corpus has been taken from one of the first PBL sessions when group 4 are discussing a case based on material and energy balances. Extract 6.3 shows an instance where the participants refer back to an email they have received from their tutor regarding the case at hand.

Extract 6.3: Group 4 - Material and Energy Balances 14:52 - 15:08 (031017D1)

1	Grant:	did you guys see what like Erica *((the tutor))*
2		posted this morning
3	Adam:	yeah like people getting stuck on it like quite
4		a lot
5	Emily:	what was it
6	Grant:	basically it's
7	Adam:	she says that basically she's been getting a lot
8		of emails from people saying like what do you do
9		for the case two and stuff so yeah I think we're
10		on a good track then
11	Grant:	yeah
12	Nick:	yeah but I don't really think we had anything
13		stopping us but we were just kinda
14	Adam:	yeah it'd be useful if we had that

Extract 6.3 begins with Grant asking the group "did you guys see what Erica posted this

morning", Erica is the course leader who had previously sent the class a message with some more information on the case to help guide the students on their self-directed learning (independent research). Adam replies in line 2 and 3 discussing the content of the email, "people getting stuck on it like quite a lot". This is followed up by Emily asking "what was it" and is answered by Adam in his longer utterance from line 7 to 10. Again there is another mention of "she" in line 7 when he starts to describe the announcement, specifying "she says that basically she's been getting a lot of emails from people saying like what do you do for the case two" this explains why they have received more information about the case. Adam then leads into an evaluation of the group's progress when he says "so yeah I think we're on a good track then" in lines 9 and 10. It can be inferred from this that he is actually using the knowledge from the course leader that other groups were struggling to make a reflection on their achievements and since they have not had trouble they are doing well.

6.2.3 Discussing the Written Feedback

One important part of the PBL process is making sure that the students receive feedback on their learning objectives to ensure that they are covering the intended content in their self-directed learning. There is an assumption that this feedback will be read, discussed and acted upon to help inform the team's independent research. This strategy has been described in section 5.2.5 on page 116 and examples demonstrated how students from the first round of data collection would use the feedback to reflect on their PBL process.

An example of when the students are talking about their written feedback can be seen in extract 6.4. This extract has been taken from a session when group 3 were reporting back their research into equipment specification sheets.

In extract 6.4 Eva orients to their feedback in the first utterance saying "on her like feedback sheet she like suggested putting like LO1a and LO1b" in line 1 and 2. This shows how she has read and acted upon the feedback they have been given. Especially because Aaron's short response in line 4 means that Eva continues and says "so I labelled them as that". It shows how a very explicit change has been made, to the team's objectives and therefore the summary submission, based purely on the feedback from the tutor. Jamal

Extract 6.4: Group 3 - Equipment Spec Sheets 10:00 - 10:22 (301017AUD2)

1	Eva:	for like our case 10 as well on her like
2		feedback sheet she like suggested putting like
3		LO1a LO1b and stuff
4	Aaron:	ok
5	Eva:	so I like labelled them as that
6	Richard:	alright
7	Jamal:	wait why would you oh so if they're related
8	Eva:	cause there like similar yeah so this is just
9		for like the what is ones but we had it as
10		one LO and she said LO1a and LO1b and like put
11	Jamal:	I forgot she gives feedback
12	Eva:	ah yeah

appears confused about this idea, seen in line 7 "wait why would you oh so if they're related". He does seem to clarify quite quickly what Eva means but she also provides a more detailed explanation in lines 8 to 10. When Jamal then responds in line 11 confessing "I forgot she gives feedback" it is clear to see that he had not looked at the written feedback so was not aware of the change which had been proposed.

This example shows two different attitudes in this respect, some of the group are aware and making use of the feedback. Whereas others namely Jamal show more independence in their PBL process since there is less reliance on receiving input from the 'expert'.

6.3 Data-Driven Findings

Since the analysis for this work was conducted using a combination of methods, see section 3.4 for more details, there are some findings which emerged solely from the data itself. These are the strategies outlined in this section, and due to the order of analysis some may have already been described in chapters 4 and 5. The particular strategies described in this section have been visualised and highlighted in fig. 6.2 as shaded yellow boxes with a solid outline. Here the strategies are described and example extracts are provided to represent how they were used during the reporting sessions for the second round of data collection.

6.3.1 Effort Regulation in Talk

Observed in all the analyses, the students either downplay the complexity of tasks or attempt to minimise the effort required of them. This has been summarised in sections 4.3.1 and 5.3.1 on page 96 and on page 121. It has also been identified in the reporting phase for the second round of data collection. The example in extract 6.5 shows how effort regulation was observed in this specific context.

Extract 6.5 is an excerpt taken from a session when group 3 were discussing a case based on the environmental considerations involved in chemical process design.

Extract 6.5: Group 3 - Environment 6:42 - 7:39 (131117AUD2)

1	Jamal:	should we are we splitting up all the shit for
2		all the cases or
3	Eva:	I've already split it up for case 13 and 14
4	Aaron:	13 and 14
5	Jamal:	ok
6	Eva:	I just like assigned it to people
7	Jamal:	nice
8	Eva:	I think you've only got two unless there is three
9		but you and Conor's like third one is just making
10		the document and then I think yours seem slightly
11		bigger that's why there I just like did the
12		names all random
13	Jamal:	how many do you have *((to Eva))* none
14	Eva:	see I've got three I've got three research ones
15		actually
16	Jamal:	alright

In extract 6.5 Jamal initiates the conversation asking "are we splitting up all the shit for all the cases" (see line 1 and 2); a clear demonstration of trying to divide the tasks between the group to reduce their individual workload. Eva replies and substantiates this since she has "already split it up for case 13 and 14". In line 6 Eva says "I just assigned it to people" implying that she delegated the work to different team members. After receiving little response (line 7) from the team Eva then justifies and elaborates on this (lines 8

to 12) by explaining the number of learning objectives that Eva assigned to each team member. This appears to cause some trouble since Jamal then asks directly to Eva "how many do you have none" insinuating that Eva has not or will not be taking her share of the responsibility. Again Eva has to justify her actions and explains that she has taken on an equal part of the work "I've got three research ones actually". Jamal does reply "alright' acknowledging Eva in line 16.

Extract 6.5 shows the organisation and negotiation of the team's workload. This is representative of many conversations which are focused on the 'divide and conquer' approach to the PBL process. This demonstrates how desirable it is to reduce the team's workload but can be detrimental to the learning process because it could lead to gaps in individuals knowledge when only researching and addressing one learning objective.

6.3.2 Reference to Books

One key aim of problem-based learning is to promote the search for a variety of resources when students are conducting their self-directed learning. There were rare attempts for students to refer to expert sources of knowledge during the brainstorming phase of PBL but this improved when the teams were reporting back after the self-directed learning phase (see chapter 5).

There was an increase in time spent discussing books, specifically textbooks or the recommended reading. This was present during the first round of data collection and examples can be seen in extract 5.11 on page 124 and extract 5.12 on page 125. This section is looking at how this was observed in data and transcripts from the second round of data collection.

Extract 6.6 has been taken from a session with group 4 early in the semester. The case at hand was intending to introduce process design basics.

The discussion in extract 6.6 is initially related to how the team might be able to present the summary of their research. In line 1 Nick orients to this when he says "we'll think about how we're gonna write it down". Following this is when the team first mention

Extract 6.6: Group 4 - Process Design Basics 06:51 - 07:42 (021017AUD1)

1	Nick:	we'll think about how we're gonna write it
2		down
3	Adam:	wait right that that book Coulson Richardson
4		literally step by step if we just follow it
5	Emily:	Coulson Richardson I've got that on PDF
6	Adam:	yeah same so
7	Emily:	uh so we can get the numbers have some numbers
8		from that
9	Adam:	cause erm that literally tells you exactly what
10		to do and you just get what you need
11	Emily:	that's a really big learning objective that
12		somebody is gonna have to take on but I don't
13		mind doing that one cause it's literally just
14		reading it and writing it down
15	Adam:	yeah

the textbook, Adam states in line 3 and 4 "that book Coulson Richardson literally step by step if we just follow it". Presumably, Adam here is suggesting that they could summarise their work in a similar manner to examples shown in Coulson & Richardson (2005). The conversation then goes on a tangent discussing the book, when Emily says "Coulson and Richardson I've got that on PDF" (line 5) and Adam agrees "yeah same so" (line 6). The conclusion being that the team have access to the book so it can be used to help with their submission. Adam explains how the book can be used in lines 9 and 10, "that literally tells you exactly what to do and you just get what you need" where 'that' refers to the textbook previously mentioned. Emily then elaborates in lines 11 to 14 discussing how this might be "a really big learning objective" but "it's literally just reading it and writing it down". This is very telling since it makes it clear Emily is planning to use the book as a primary source to address one specific learning objective.

The reference to books as a resource shows the PBL groups are managing to find and make use of relevant sources of knowledge to help them with the PBL process. This occurs regularly in the reporting phase of PBL and has for all groups in both rounds of data collection. It is a good indication that the students are aware of where and how to find

reliable and expert sources of knowledge. It happens that the example in extract 6.6 shows Adam and Emily discussing how they can make use of the specified book in the future when completing their summary, whereas the examples from section 5.3.3 on page 123 show the teams explaining how they had already used the books to tackle the learning objectives.

6.3.3 Using the Internet

Not only do the students turn to books to help them address learning objectives but they also discuss how they have used the internet for this purpose. This again has been a consistent finding for both rounds of data collection but was something lacking in the earlier brainstorming phase of problem-based learning. The addition of the internet shows that the participants were capable of calling on a variety of resources to complete their self-directed learning.

Extract 6.7 is from one of the first PBL sessions where group 3 were reviewing their learning on process design basics, including what it is, why it is relevant, how it might differ from equipment design and the use of design projects in chemical engineering.

Extract 6.7: Group 3 - Process Design Basics 17:51 - 18:30 (021017W2B)

1	Aaron:	take it with a pinch of salt ok Wikipedia
2		chemical engineering process design is
3	Eva:	oh
4	Aaron:	process design is distinct to equipment design
5		so there's definitely a difference
6		*((Aaron and Jamal looking and reading from*
7		*laptop screen))*
8	Jamal:	yes
9	Aaron:	erm equipment design which closer in spirit to
10		the design of unit operations er
11	Eva:	erm
12	Jamal:	processes often include many unit operations

Extract 6.7 opens with a disclaimer "take it with a pinch of salt ok" from Aaron in line 1 and he immediately follows this with "Wikipedia chemical engineering process design

is". It appears that Aaron is currently attempting to find through Wikipedia what chemical process design is. This may seem discouraging since Wikipedia can be unreliable but the disclaimer which prefaced his information shows that Aaron does know that it might not be correct. He is thinking critically about this source of knowledge. It indicates that they may have just been looking at this to get some idea to trigger further more detailed research and he has an awareness that the information will need to be validated with a more reliable source.

The extract then leads into both Aaron and Jamal reading out loud the information from the web page as seen on a laptop to help the group understand the fundamentals of process design. This is representative of how resources were discussed in the PBL teams conversations from the second round of data collection. They were often used in real-time during the PBL session itself or referenced to be used in future to complete their summary. In contrast, when the internet or online sources were mentioned in the first round of data collection it would be a source they had already used as evidence to verify the information reported back from an individual's research.

6.3.4 Other Groups

Similarly to when students refer to the tutor as a method of evaluating their processes they often compare themselves to other PBL teams or quote other friends from the class. The earlier examples taken from the first round of data collection can be seen in chapter 5, extract 5.12 on page 125 and extract 5.15 on page 129. These extracts have shown how the teams from the first round of data collection would compare the content which other PBL groups were researching and how the team worked together respectively. In the second round of data collection, this happened almost identically where the teams would compare their efforts both in respect to the content of the summary and regarding their group processes.

Extract 6.8 gives an example of when group 3 were talking about the knowledge which other PBL groups have included or used when approaching a particular case. Group 3 are reporting on a problem case where the team had to understand and practice the method required to check a material balance for a given process.

Extract 6.8: Group 3 - Material and Energy Balances 13:18 - 14:39 (021017W2B)

1	Richard:	there's other groups that have put like alpha
2		they've done it with alpha and stuff
3	Jamal:	oh
4	Richard:	but yeah yeah I
5	Jamal:	how have they done that how have they
6	Richard:	over everything and I was like are you for
7		real
8	Conor:	surely not
9	Richard:	but they you can only do so much because you
10		don't know about your you don't know enough
11		information about your recycle streams
12	Jamal:	that's not
13	Richard:	to actually do that I don't know I didn't see
14		the working but I heard discussions
15	Jamal:	oh ok

Richard opens the conversation with this reference to other PBL groups on the module, in line 1 he states "there's other groups that have put like alpha they've done it with alpha and stuff". The concept of using alpha, the extent of reaction, as the unknown when conducting a material balance is a method learnt in the first year but the students would never have had to apply this to such a complicated problem (see PFD for case 2, appendix **??**). The response from Richard's fellow team members shows how surprised they are that this method could be considered achievable. Jamal in line 5 says "how have they done that how have they" as if he is in awe of this possibility and Conor even more in shock exclaims "surely not" in line 8. Richard himself appears confused when he says "I was like are you for real" in lines 6 and 7 and he later expands on what he had learnt from the other groups in lines 9 to 11, "you can only do so much because you don't know about your you don't know enough information about your recycle streams". Met with little response he continues once more explaining "to actually do that I don't know I didn't see the working but I heard discussions" so Richard here is confessing that although he has gathered some knowledge about how other students are attempting to tackle the case he is not confident regarding actually applying this new knowledge. This example shows

how observing and questioning other PBL teams about their approach has only concerned the group given that they are not aware or comfortable with this course of action.

This is a curious situation seeing as the group look to find out how other groups are managing with the PBL pedagogy but that this might not inform their working process. It is a method used really to measure how well the team might be working compared with other teams completing the same work and it shows how inherently competitive the groups are.

Extract 6.9 shows an instance from the second round of data collection when group 4 are comparing their own working processes to that of other teams in the class. This was taken from a PBL session when the group were discussing process design fundamentals.

Extract 6.9: Group 4 - Process Design Basics 07:16 - 07:45 (021017AUD1)

1	Nick:	sorry you know that we've written way more than
2		other groups
3	Emily:	yeah
4	Nick:	which I'm fine with but
5	Adam:	yeah
6	Nick:	like they're writing like the guys just in that
7		room or whatever
8	Adam:	mhmm
9	Nick:	erm they're writing like two sentences per
10		learning objective or like two or three
11		sentences and we're like writing like
12	Robert:	two hundred words
13	Nick:	well for one there's literally a page
14	Adam:	yeah so yeah I
15	Nick:	no I'm fine with that it's great it means we'll
16		get a better mark but
17	Robert:	well we can when erm whoever comes in since
18		we've got a completed one now we can just show
19		her *((the tutor))* and see like is this the right
20		guidelines

Nick begins this discussion announcing "we've written way more than other groups" (lines

1 and 2), he seems to be congratulating the team on their efforts and the quantity of content they have produced for the summary submission. Emily responds saying “yeah” in line 3, prompting Nick to carry on he says “which I’m fine with but” in line 4. This utterance insinuates that Nick might be looking to amend their current working habits because they are different from the other groups. The rest of the team members offer little reply (Adam lines 5 and 8). So Nick explains even further, line 9 and 10, claiming another group have been “writing like two sentences per learning objective” compared to their own “two hundred words” as Robert states line 12. This shows direct comparison and it does appear that Nick is trying to persuade the team that they might not need to be writing this quantity since other teams are not. In line 15 and 16, Nick comes in quickly backing down from this idea when he says “no I’m fine with that it’s great it means we’ll get a better mark” justifying why it would be better continue working in the same manner. Robert then gives a temporary conclusion to this when he refers to the tutor in lines 17 to 20, suggesting that they check with a tutor to see if their work is following the guidelines.

The second example seen here is more involved in how the teams are presenting the work rather than the content that has been included. It shows how the teams use knowledge of what other class members have done to assess their progress. In this particular situation, it could legitimise reducing the amount of effort or time the group give to each case because ‘everyone else’ has done less.

This comparison and reference to other PBL teams convey a sense of competitiveness and a feeling that the students wish to all achieve at the same level, an average level. That doing too much is undesirable but so is not knowing what to do when there are other people who do.

6.3.5 Reflections on the Group Process

In the previous round of data collection, it was found that the groups tended to follow a very clear and specific sequence in their reporting sessions, the details of the components that this included were presented in section 5.3.6 on page 130. This was comprised of contribution prompts (extract 5.16 on page 131) where participants were named

and asked to provide their contribution to the PBL case followed by long elaborations (extract 5.17 on page 133). An additional aspect of this is the presence of reflections on the group's processes which would occur towards the end of these PBL sessions.

During this second round of data collection the reporting sessions of PBL are not conducted with such structure, contribution prompts and elaborations were not observed in the data. The one aspect of this sequence which was present during this second round of data collection happened to be the reflections on the group's process.

The example included for this finding, seen in extract 6.10, has been taken from a session where group 4 were focused on the details and development of process flow diagrams.

Extract 6.10: Group 4 - Process Flow Diagrams 02:20 - 03:01 (101017D1)

1	Emily:	er the reflections for case four I need your
2		ideas if anyone else if an if anyone else has
3		anything let me know anyone wanna say
4		anything about the reflections for case four
5	Grant:	mm reflections
6	Robert:	um just figuring out what a process flow sheet
7		was and the a big word a big word I can't say
8	Grant:	yeah
9	Liam:	know what you're talking about
10	Robert:	ha
11	Grant:	I guess we can maybe talk about something about
12		how you sort of have to do the first bit of the
13		problem before you can really do anything else
14	Robert:	mhmm
15	Grant:	you have to be like right so what is the
16		process flow sheet and what are the things and
17		then you can sort of make logical sense
18	Emily:	can I also say erm in future if we're given
19		like a program something we need to use we
20		need to get to grips with it quicker
21	Nick:	yeah

Early in the PBL session, Emily asks for ideas on the reflections which need to be included in the summary submission, she says “let me know anyone wanna say anything about the reflections for case four” in lines 3 and 4 (extract 6.10). This is similar to extract 5.18 on page 135, but the question is less immediate as they are now required for the summary submission and it is not part of the ‘learning objective forms’ (see appendix A.4.2). This results in Robert (lines 6 and 7), Liam (line 9) and Grant (lines 11-13 and 15 to 17) giving serious and thoughtful ideas about what could be improved or done better for the next case. They were mainly discussing how they need to work more on fully understanding what the case is asking of them before the self-directed learning, this was summarised by Grant in lines 11-13. Emily rejoins the conversation in line 18 to 20 with her recommendation “in future if we’re given like a programme something we need to use we need to get to grips with it quicker”.

The example is shown in extract 6.10 shows a collaborative effort with a number of team members discussing their thoughts on how the team have worked and evaluating the PBL process. It appears like these are actually thoughts which team members agree need to be improved rather than the superficial ideas demonstrated in section 5.3.6 on page 134. This difference will be examined in more detail within chapter 7.

6.3.6 Grades

This section describes how motivation is implied through conversations, students talk can be analysed to see what they deem important as reasoning for their actions. In particular, the participants would legitimise their efforts or a lack of effort since they did not see enough incentive or motivation.

This has been seen briefly in previous extracts from this chapter and more key examples can be seen in extracts 6.11 and 6.12 which have been described below.

Perhaps the most intriguing finding from this analysis and one unique to this round of data collection was how often the groups refer back to their grades or the marking scheme. They regularly link back to what the work is ‘worth’ or how they can correctly hit the mark scheme (see appendix A.7). The previous year the teams had been asked just write a summary of their findings and discussion for the case each week but for this academic

year (commencing September 2017) the groups had to produce a document which was peer marked and counted to their final grades.

There have been a few examples when 'marks' or 'the marking scheme' have been mentioned in the extracts included in this chapter. The first can be seen in extract 6.2 on page 143. In lines 9 and 10 Jamal states, "a lot of the marks for that one is about the content of the presentation". Here he is attempting to change the plan of action and encouraging the group to spend more time on the 'content' of the presentation (which happens to be regarding what process design fundamentals) because that is what equals more marks. There is no point where the students acknowledge it might be beneficial for themselves to research and learn about these basic aspects of chemical process design for future transfer to professional work in the industry.

The second example of this can be seen in extract 6.9 on page 153. In line 15 and 16, Nick says "I'm fine with that it's great it means we'll get a better mark". Nick here is legitimising the higher quantity of work produced since that automatically means higher marks, at least in the minds of the students.

Another instance has been presented in extract 6.11 to demonstrate how the concept of the mark scheme can influence the working process for a team. It has been taken from a session where group 3 were working on process flow diagrams.

Extract 6.11 starts with Aaron asking the questions to gather the team's reflections. In line 1 and 2 Aaron asks "have you had any major problems like major setbacks" this is an indirect question used to prompt the team to reflect and evaluate their processes. After Aaron and Richard have established this is related to case 4 (lines 3 to 5). Eva replies to the original question "not really" in line 6 suggesting they have not had major setbacks. Richard then agrees and elaborates in lines 7 to 9, he explains the current position the work is in "it's all there like all the information's there it's just carrying on sifting through and putting it together". In response to this Aaron is justifying why it is necessary to write these reflections not because it will help them to improve their process and master the PBL pedagogy but since "the quality of content in this is worth the exact same as the reflection" (lines 10 and 11). The team understand this because there are four aspects to the marking

Extract 6.11: Group 3 - Process Flow Diagrams 11:38 - 12:25 (101017D2)

1	Aaron:	have you had any major problems like major
2		setbacks
3	Richard:	case 3 or 4
4	Aaron:	4
5	Richard:	4 erm
6	Eva:	not really
7	Richard:	not really it's just kinda it's all there like
8		all the information's there it's just carrying
9		on sifting through erm putting it together
10	Aaron:	it's just see all the quality of content in
11		this is worth the exact same as the reflection
12	Eva:	yeah
13	Aaron:	and as well the exact same as references

scheme, each which must be marked out of ten so they are equal in weighting. He is persuading the group that time must be spent on writing reflections due to the number of marks it is worth not because it is a major aspect of PBL or because evaluation could truly inform and help improve their future work.

The examples described in this section give clear indication that the students are often if not always thinking about what the work is 'worth'. They appear to often be using the incentive of grades as motivation to spend time on a particular aspect of the PBL case. Rather than the students looking to become knowledgeable in all aspects of chemical process design for their fourth-year project or work in the industry, what dictates the teams focus is in fact what might help them to merely pass the course. There appears to be no desire to become expert with the content or the pedagogy.

The final part of this section shows a deviant case which contrasts the examples above. Extract 6.12 shows one team member, Emily, from group 4 arguing that the cases need to be worth more or there should be less of them to complete. It has been taken from a session when the team were discussing a case on heat integration and energy recovery.

The extract starts amidst a conversation about the module administration, in particular the

Extract 6.12: Group 4 - Heat Integration 29:38 - 30:35 (061117AUD1)

1	Emily:	if you did like maybe seven or eight instead of
2		fifteen and then we can like spend more time
3		on them make them better
4	Adam:	mhmm
5	Emily:	and it's justified that they're worth fifteen
6		percent or either make it worth like twenty
7		twenty-five percent
8	Robert:	well I think I dunno I think the thing about the
9		cases is that they're not really there for marks
10		they're there to teach us and the alternatives
11		would be like so many lectures so we'd still
12		be like using time on but it wouldn't be worth
13		anything and then there'd be more input based
14		on the
15	Grant:	the design project
16	Robert:	the design project
17	Nick:	getting marks for
18	Robert:	yeah and that'd be like I used to be like that
19		as well but I think thinking about the cases
20		in terms of getting marks for them isn't
21		really what they're for I guess
22	Nick:	yeah
23	Emily:	I know but and that's fine and I can understand
24		that point of view but I don't understand we're
25		being and I'm not saying just for me I'm
26		saying in general how are you supposed to
27		motivate people to put a lot of effort in
28		with the stuff and do something about it if
29		they're gonna get one percent from it
30	Grant:	I guess the issue was that last year they were
31		worth zero so obviously it's a fraction because
32	Emily:	yeah

number of cases and what the case summary submissions are worth. Emily has just been asked what she would prefer to do to improve the module, her reply is seen in her first two utterances, lines 1-3 and 5-6 of extract 6.12. Her propositions are to either reduce the number of cases for the purpose to "spend more time on them make them better" (lines 2 and 3) or "make it worth like twenty twenty-five percent" (lines 6 and 7). These recommendations suggest the current workload is not equivalent to its 'value' since it only contributes fifteen percent to the final grade. It implies that there is an unwillingness to put the effort in and work hard if there is not this external incentive.

Robert's utterance (lines 8 to 14) presents the counter-argument which shows a more promising view on the purpose of PBL. His key sentiment is the idea that "the thing about the cases is that they're not really there for marks they're there to teach us" in lines 8 to 10. This demonstrates that Robert has a greater understanding of the objective of PBL. He strengthens his point further "the alternatives would be like so many lectures so we'd still be like using time on but it wouldn't be worth anything" in lines 10 to 13. This emphasises his idea and challenges Emily since the typical pedagogical approach is purely lecture-based where the work they do throughout the semester will not contribute to the final grade either (being based primarily on a final examination). Robert finishes in line 19 to 20 stating "I think thinking about the cases in terms of getting marks for them isn't really what they're for I guess" this reiterates his previous thoughts and encourages the group to think about the content and the learning process rather than fixating over the 'marks'.

Unfortunately, Emily does not change her mind about this and maintains the idea "how are you supposed to motivate people to put a lot of effort in with the stuff and do something about it if they're gonna get one percent from it" (lines 26 to 29). This plainly states that only an incentive, such as grades or marks, will motivate students to work hard on the cases. The conclusion to the discussion comes when Grant replies in lines 30 and 31, saying "last year they were worth zero so obviously it's a fraction". This solves the issue since he makes it clear that it could be worse if the cases did not contribute so they should be grateful that they are now.

This is one of the rare instances where the team members suggest that it could be useful to

complete the cases for a different purpose, that there could be other sources of motivation for them rather than just because they are graded.

6.4 Summary

This chapter has presented and described the strategies which were identified and observed during the reporting phase of PBL for the second round of data collection. These strategies were originally seen in fig. 6.2 and are again summarised in table 6.1.

Table 6.1: Summary of the strategies identified from the analysis of the Round 2 reporting phase data and how these are clustered to form larger categories.

Organisation	**Resources**	**Typical Sequence**	**Motivation**
Effort	Tutor	Reflections	Grades
Regulation			
Facilitation	Books		
	Internet		
	Feedback		
	Other Groups		

The majority of strategies observed in these analyses were related to the use of learning resources during the discussion of students self-directed learning. The resources identified were of a great variety and align with those used during the first round of data collection. In this particular context, however, the resources were often used during the PBL session or discussed as a source that can be used to help the team in their future work. They were rarely used to validate or reference the knowledge they had acquired during individual research.

The key finding from this unique analysis was how the impact of a graded summary was so apparent when examining students' talk. There were regular orientations to the marks or marking scheme for the summary notes, this was used as an incentive for the team to work on particular aspects of the cases and negotiate where their efforts would be best placed.

The next chapter delves into these results in more detail, providing critical discussion and

comparison on the findings presented in chapters 4 to 6.

7 | Discussion

This chapter provides a discussion of the findings as reported in chapters 4 to 6. These correspond to different analyses given the specific context of the data being studied. Firstly the interpretation of these results is included for each chapter, to further clarify and discuss the findings. This is followed up with a comparison between the three different analyses in section 7.4. This shows the comparative analysis for the distinct phases of PBL, brainstorming and reporting, and also how behaviour changed in different rounds of data collection.

7.1 Brainstorming Phase of PBL

The first analysis chapter (4) in this thesis reports on the data, in the form of transcripts, which correspond to the brainstorming phase of PBL. This is a session where the teams receive a case based on a topic within chemical process design and must work collaboratively to define the problem and formulate learning objectives which will be studied during the teams self-directed learning. The strategies identified in the analysis of these brainstorming sessions are summarised in fig. 4.2 on page 81 and table 4.1 on page 107. This section will explore and discuss these findings in more detail.

A key finding from this analysis was the importance of organisation during their PBL sessions. The organisation was dominant during the brainstorming phase of PBL, in particular, there were many instances of prompts to stages of the PBL cycle and attempts at facilitation. This helped the teams progress through the different aspects of PBL and added structure to their sessions. The teams spent time trying to establish what was expected to be achieved during each of these stages and used the keywords as prompts

to address these expectations. The major focus for the sessions happened to be regarding the processes involved in the pedagogy and the uncertainty students feel around such an unfamiliar setting. The emphasis held on adding structure allows the teams to manage and minimise this uncertainty. There may be a point in time when the students become comfortable enough with the PBL process that this structure would be unnecessary but it is extremely important since the teams were having to adapt to the new pedagogy and a whole new way of working.

One learning from this analysis is the understanding of how crucial the scaffolding of the PBL process is. The way the students make use of the PBL cycle and the 'learning objective and summary' forms to navigate the PBL sessions demonstrate just how significant these are. This is especially important when a 'floating facilitator' is used since the majority of the time the teams are responsible for their own progress.

Barrows (1988) describes the tutorial process highlighting specifically the role of the facilitator in problem-based learning. In the context of this thesis, there is no facilitator present to question the learners throughout the session and prompt their higher-order thinking skills. This is why the students are provided with these particular prompts on the 'learning objective and summary' forms. Along with the PBL cycle, these are the main methods of providing scaffolding and guidance to the teams. Careful consideration must be made to ensure that these cues are having the intended effect and helping the students to direct their PBL sessions. The students' dependence on scaffolding is further exemplified through their reliance on the tutor as a resource for more information.

However, one potential issue about the use of this finding is that these support 'prompts' might be narrowing the scope for the teams' discussion, limiting the depth of the learning. By focusing closely on the process and PBL expectations they are less likely to be conducting critical discussions on the content of the case which could lead to the team missing out some details relevant to a case. This has been the main concern about the implementation of PBL within engineering because putting direct responsibility of the student's learning in their hands may lead to fragmented knowledge if topics are not covered as expected (Perrenet et al., 2000). Providing feedback to the students on their learning objectives is one particular measure that is in place to mitigate this concern and

ensure that the teams are addressing all the intended learning objectives.

7.2 Reporting Phase Round 1

Chapter 5 presented the analysis of the data for the reporting phase of PBL, where the teams reconvene to share and discuss their individual research. The teams have a different aim in this situation since they are no longer working with an unfamiliar case and are reporting back their new knowledge. This meant there behaviour and discussions also changed in line with the expectations.

In the reporting sessions (Phase 3 of PBL, seen in fig. 3.1c) the groups were much less focused on their organisation and the stages of the PBL cycle. These things were still observed but the dominating aspect of the reporting sessions (from the first round of data collection) happened to be how the teams coordinated their discussions. There was a very clear sequence of contribution prompt followed by elaboration, a process continued for every team member.

This sequence emphasises the outcome from the 'divide and conquer' strategy observed during the brainstorming sessions. The teams would first assign each team member with one or more learning objective to research, this then translated to the later reporting phase of PBL through the use of contribution prompts and elaborations. The teams had clear expectations that each member was accountable for a unique contribution as designated during the brainstorming phase. This means every team member is responsible for some aspect of the case and is asked to contribute this when they are prompted in the session.

The elaborations provided by students in these instances show examples of how the students relay their individual learning to the whole group. This could be seen as some form of co-teaching as they give a mini-lecture on their specified learning objectives. Co-teaching is included as a stage in the PBL cycle but unfortunately, the way this is interpreted and conducted by the teams does not appear constructive. The students' elaborations are entirely solo with the rest of team passively listening there are rare examples of challenging or clarifying information from another team member. Realistically

this is how the students might characterise teaching because the majority of their learning occurs through lectures, where the students are expected to listen and learn from an expert. This fits with the traditional idea that students are empty vessels to be filled up (Johnson et al., 1991). Even when one team member takes notes of this 'recitation' from individuals there is no interaction between them. The team's summary form becomes much less a common document since there is no attempt to reach a consensual agreement on what should be written down, it is only the note taker who makes this decision.

One aspect of these elaborations was how the team members would invoke and mention specific resources which they had referenced to validate their knowledge. In this situation these were all sources they had previously found and used during phase two of PBL (independent research); a combination of books and the internet as learning resources. There are times when the students would refer to specific books or websites explicitly. This makes the process transparent and means that the rest of the team would know exactly where to find more information on that particular topic. At other instances, though the students have appeared hesitant and provide ambiguous references to 'the internet' or 'the book' which are less helpful for any team members wishing to look it up in the future. An example of each of these has been presented in both sections 5.3.3 and 5.3.4. The difference between the two ways in which the students refer to particular sources could reflect the individual's confidence in their knowledge or the level of depth of their investigations. When the team members are unsure about the information or its source they might not want to state the reference directly. It was noticed in this analysis how the students used the written feedback to help them evaluate their processes or attempt to understand the level at which they are working. Feedback intends to give the students guidance on their next stages in the PBL cycle and aid the research process. However, in the first round of data collection, it was used more as a method of measuring the team's achievement either good or bad but is less often used to actively improve in future.

7.3 Reporting Phase Round 2

The analysis for the reporting phase of PBL was done here separately for each round of data collection as it was thought the changes in task requirements were significant, see

description in chapters 3 and 6. These administration changes led to actual changes in how the teams behaved so it was felt these needed to be examined as distinct situations. However, there were several similar strategies observed in all three data sets but they were regularly being used differently or to invoke specific actions, this was identified when analysing the data from the reporting phase of the second round of data collection.

This was clear when observing how the teams would mention the use of resources or refer to particular sources of information. In the second round of data collection, the students would often refer to references to look up immediately during their session or to be used for further research before submitting the summary notes. This insight suggests that the references are being mentioned to help the team progress and not to validate the information they have already found (like during the first round of data collection). The students' discussions about resources also imply that there is more research to be done and this reporting session is not the finishing point of this PBL cycle.

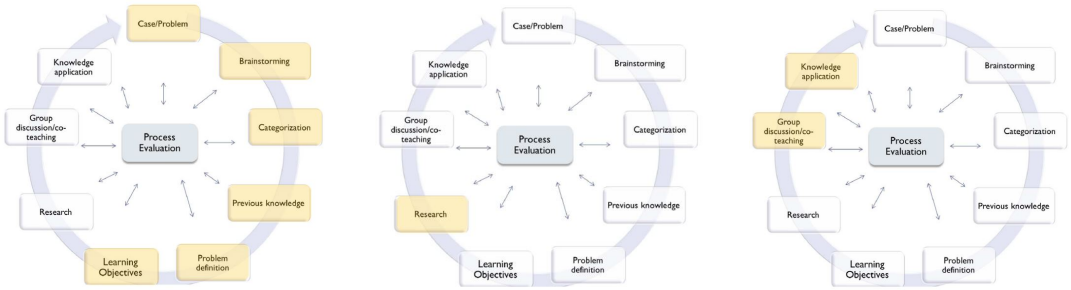
In this second round of data collection, the analysis found more utterances related to the feedback which showed the students discussing the comments and how these might be actioned for the upcoming cases. This shows promise since the group are now actively reading and using this feedback to change their process and not make judgements on their initial ideas.

Given the changes in the module organisation particularly the addition of a graded summary submission, this was used by the students as a driving force to lead the discussion in specific directions. This incentive was referred to in the conversations to persuade the team to focus or work on particular aspects of the case since they were 'worth' something. This shows a direct insight into the students' motivation since it was successfully used by team members to explain a particular course of action.

7.4 Comparative Analysis

PBL is a well-defined and well-known pedagogy that many institutions have now implemented across a number of countries and subject domains (as discussed in chapter 2. The tutorial process has been documented in several iterations, most notably Barrows

(1988) and Hmelo-Silver (2004) who have both written about the various stages involved in problem-based learning. These stages of PBL have been described in section 2.3.3 on page 36 which includes fig. 2.5, a visualisation of Hmelo-Silver model of PBL. These descriptions of PBL led to the development of the PBL cycle for the PBL implementation studied in this work (see fig. 3.1). This figure is repeated here and shows clearly the different stages and how these correspond to phases of PBL.



(a) Phase 1: Brainstorming (b) Phase 2: Research (c) Phase 3: Reporting

Figure 3.1: Phases of the PBL cycle and the stages that are incorporated into each of these phases.

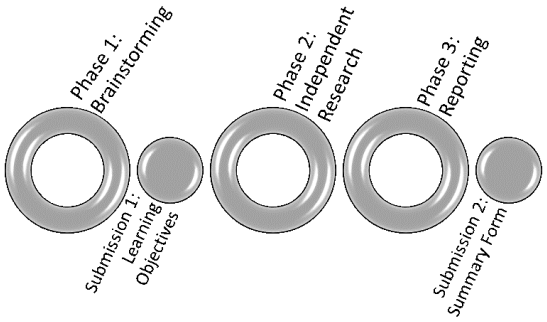
The PBL stages are rarely aligned to PBL sessions such as phase 1 and phase 3 as seen in fig. 3.1. This is surprising given that these stages have clear and varied objectives and considering learning theory, especially the concept of constructive alignment developed by Biggs (2014), explains how the objective of learning must be aligned with the activity and the assessment.

The circumstances of problem-based learning are already catered towards learning objectives aimed at improving peer interaction, collaboration and student-led knowledge discovery. However, distinct objectives are emphasised at each stage of the PBL cycle. For example, during the initial stages, the PBL teams will be getting to grips with an unfamiliar problem case focused on understanding the meaning of the case and making connections to prior knowledge. This focus moves when the teams are conducting self-directed learning (independent research) then again once the teams reassemble to share and apply their new knowledge.

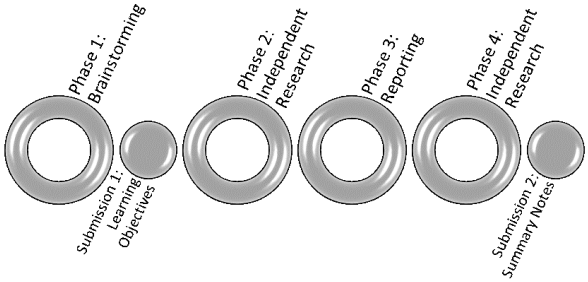
Given that the students would be trying to achieve disparate outcomes in each PBL session there was some expectation the students' behaviour would change. Hence, the decision was made to analyse the data as separate instances rather than grouping the two phases

as a 'PBL' environment it was felt better to look at them individually and identify any nuances in behaviour between them.

Once the analysis for the first round of data collection was complete and the year finished there was more understanding of how the teams were working within the PBL environment. This led to changes in how the module was managed to hopefully have an impact on the PBL groups behaviour during their sessions. This time the PBL was front-loaded to give an opportunity for the students to acquire the intended knowledge and develop their skill with the pedagogy before applying these to the group project (which was run in parallel to the PBL sessions during 2016/17). The other major change was related to when and how the team were required to submit their research findings in addition to assigning summative weight to these summaries see figs. 7.1a and 7.1b.



(a) Round 1: 2016-2017



(b) Round 2: 2017-2018

Figure 7.1: Timeline to show the phases of PBL and the submissions required for each round of data collection.

Figure 7.1 depicts the time-line to show how the addition of a summary submission affects the phases of PBL. In the first year of data collection (fig. 7.1a) the teams would come to

a synchronous session for brainstorming to discuss a new case aiming to formulate and submit the learning objectives (submission 1) at the end of this session. The team then have a week to complete their self-directed learning and independent research, the second phase of PBL. After research, the team came together for their second synchronous session (phase 3) where the teams report back their research, make notes and submit a summary to address the initial learning objectives (submission 2). This is the point where the team would then start a new case.

During the second round of data collection, the phases vary, as seen in fig. 7.1b. It begins the same with the first phase of brainstorming and the submission of the learning objectives. This round the teams were again given a week to complete their independent research before their reporting PBL session. However since the team were asked to submit summary notes for each case which would be graded, they had an extra two days of research (phase 4) before the deadline. This extends the time that students have to complete their research before needing to bring this together since the notes were not submitted at the end of the reporting session.

The following subsections discuss the differences between the behaviour of students within these different contexts. This is presented in the form the categories seen in the coding frames (figs. 4.2, 5.2 and 6.2) developed during analysis. These categories identify themes which emerged from the data and these sections discuss where they were similar or different for each analytical focus.

7.4.1 Organisation

As has been seen from the previous chapters 4 to 6 the behaviour of students did change based on the phase of PBL the teams were working within. Initially, when the teams receive the case they spend time organising themselves, all the team members are involved in giving ideas for the content the case relates to and how it can be addressed. The more promising findings include how the teams identify gaps in their knowledge and use the prompts to guide the team to different stages in the PBL cycle.

Despite this, there were also strategies identified which do not appear to aid the PBL team progress but are used by the teams to manage their process and may have a detrimental

effect on the overall learning. This is demonstrated through the team's reliance on a leader (often a role which was taken up by the same students), it appears the team require continuous prompting to stay on track and avoid the students attempt to minimise the effort which the team must give to the case and corresponding research task. The advantage or disadvantage that these strategies have during the teams brainstorming sessions is not the concern of this section, which is focused on how they differ to the strategies in place during the reporting phase of PBL when the team members are working to share new knowledge. The reporting phase of PBL is more concerned with how the students relay the information they have gathered through their independent research and through analysis of these sessions it has been observed that they are managed in a contrasting way.

In both brainstorming and reporting, there are regular prompts by students to facilitate the PBL processes, this is since the teams do not have a designated expert facilitator so they assign a team member to take on this responsibility. In each phase, these facilitating prompts are guiding to alternative outcomes. During brainstorming the prompts are mainly invitations asking for ideas on problem definition and formulation of learning objectives from the whole team. In contrast in the reporting session, there is an expectation that each team member must contribute thus the prompts are specifically asked to a person or about a particular topic which has been assigned to one group member. The teams switch from everyone being unfamiliar and new to the case topic to a place where each member should be well-read on one particular aspect of the case. This prompting keeps the students accountable for completing their work but it results in a session which appears no longer as a team activity. Instead, this reporting session becomes a show and tell with the students taking turns to relay their information. This is a concern when implementing a PBL approach, which was summarised neatly by Barrows (1988).

> *The power of their new learning will be lost if they just sit there and, in essence, lecture to each other about what they have learnt in their study (Barrows, 1988, pg. 39).*

These differences give evidence to illustrate how the purpose of each session can lead

to significant changes in behaviour. It is observed in the data how the students revert to the traditional individualistic mode of learning almost undermining the sense of the group since everyone has their own task. This same phenomenon has been identified by Skinner et al. (2015) after gathering data through student interviews it was found that the perceived purpose of the group in PBL was actually to bring together individuals research work and not to learn through interactions.

The swap to an individual goal rather than group goals begins in the brainstorming session when the teams most prominent course of action is the process of 'divide and conquer', here the case and the group are split so each person has responsibility for one aspect.

Interestingly in the second round of data collection this 'divide and conquer' technique was also identified in the reporting sessions, the teams demonstrate the idea of splitting up work in their conversations. The presence of this strategy during the reporting phase of PBL implies that the teams are delaying this decision. Though in this context it was less about which learning objectives a team member must research instead the teams were assigning objectives to be written up for the summary notes. This could be a consequence of the delayed submission as seen in the timeline, fig. 7.1b. Since the teams are not having to finish the case in the second session there is less need to divide the workload in the earlier PBL session.

There was also a difference between the focus on the written record, in the brainstorming sessions and in the first round of reporting sessions there was some concern about whether enough or the correct content was being written down. This was no longer present during the reporting sessions from the second round of data collection. This is not surprising since there was no longer a submission at the end of this particular PBL session, instead the teams were making plans and actions for who would write and what would be included in the summary notes which had to be submitted in a couple of days.

7.4.2 Resources

It was expected that the students would be more likely to talk about a variety learning resources in the reporting phase of PBL since this happens after the students have had time to complete their research and gather sources on the case topic.

When brainstorming the participants only acknowledge a few sources of information, those which were brought up in conversation were often provided by the tutor during the session itself. For example, the case material or tutor conversations. This meant that their prior knowledge was also key for progress in understanding the material, which was hinted at within the case or by a tutor. There appeared no active attempts to search immediately for more information within this session preferring to use only the resources they already have to define the problem and formulate learning objectives.

This changes once the teams have completed their research so the teams can now back up the new knowledge with sources. In both rounds of data collection, the team members referred to a wider variety of resources, particularly making use of internet sources and textbooks. Most utterances when a team member would relay their information the individual would also mention where it came from to validate the source and the content.

The types of resources mentioned during the reporting phase of PBL were the same across the two rounds of data collection, including internet sources and textbooks amongst others. However, the context in which they were referred to did change. In the first round of data collection, the teams would mention resources as a way of validating their new information, discussing when they 'had' used specific resources or where their content was 'found'. While in the second round of data collection, the teams would mention sources as they were using them or as resources which could be useful for further work. This could show more recognition for future transfer if these sources are seen as integral to their project work and need to be documented. It could also be that the later submission means the PBL groups are less inclined to complete their research before this reporting session since they have extra time before the submission of notes.

In reporting sessions it was also identified that the teams would refer to their feedback, the comments they were given on their learning objectives. This was a resource which was not referred to during brainstorming since these comments were specifically related to the last week's case so did not appear directly relevant to the new scenarios. In both rounds of data collection, the students used the feedback as a method to reflect and evaluate their PBL process. There are however instances in the second round of data collection when

students appear to use the feedback to actively change their course of action. This could have been because during the first round of data collection the reporting sessions were too late for the team to look at taking actions on the feedback. After all, that would have needed to be done before this phase of PBL.

The feedback is particularly important in this context since this module uses a 'floating facilitator' approach where there is not a tutor present throughout their session. Providing students with feedback is one of the methods used to ensure the students are covering the intended content during their independent research. It is encouraging to see the students engaged with this feedback and taking it on board.

Another resource which was used as a strategy to help the teams assess their progress was using comparison to other PBL groups in the same class. Regularly the participants would discuss plans or methods that they had heard from other PBL groups. The example extracts 5.15, 6.8 and 6.9 show instances where one team member will mention another group's progress which leads to the team comparing their ideas to that of these other groups. These extracts indicate the presence of competitiveness against the other teams in their class since they are used as a technique for students to evaluate their effort or progress in a particular case. Despite this there is evidence to show how interactions with other groups can bring novel ideas to the team, it highlights how the students can look further than their team members and learn through wider peer interaction. This emphasises the theory that knowledge is unique for every person, one group may not have considered a certain cause of action but can learn about this through other classmates.

7.4.3 Academic Previous Knowledge

Gijselaers (1996) discuss how the activation of prior knowledge shows evidence of learning as a constructive process; activating previous knowledge aids the processing of new information since connections can be made. Problem-based learning as a pedagogical approach has been found to promote the activation of academic previous knowledge (Dolmans et al., 2005; Dolmans & Schmidt, 2006; Schmidt, 1993). These are the reasons why it was expected to be integral to students PBL sessions.

Through analysing learners naturalistic processes, it was found that this activation was verbalised within conversations. There were instances in both phases of PBL where individuals would refer to specific modules or topics they had previously studied. This could have been used to help other students make connections between the new case and their previous studies. There were also references to the content the teams had covered in the previous week's case. There was no distinct difference between how these familiar aspects of the case were mentioned in the contexts for each analysis.

There were some concerns when coding this strategy however since presumably, all the participants' utterances will have some element of previous knowledge. However, the importance of this in-group learning is when the team members explicitly discuss or mention a specific aspect of their previous knowledge. To ensure that the participants were oriented to their previous learning the utterances coded were only those where they publicised the connections to particular moments in time or modules they had completed.

7.4.4 Shared Understanding

The pursuit of shared understanding is, in essence, the ultimate objective of peer-learning and collaborative pedagogical approaches. The students need to work in a team during their PBL sessions to reach common ground and formulate learning objectives as a collective group. If there is no attempt to reach a shared understanding of the problem or tasks this may indicate the team is working separately rather than aiming to reach a collective goal.

In this study, the strategies categorised within shared understanding were only observed and identified during the brainstorming phase of PBL. During the first phase of PBL, there is much uncertainty, the teams are working with a new topic while also navigating through problem-based learning processes for the first time with an unfamiliar team. There is a need for the team members to work together to clarify and understand the ideas and beliefs of every student.

One aspect of this shared understanding was how the teams would directly indicate and recognise a gap in their own or the team's knowledge. This would only appear directly

relevant to the initial stages of PBL when the topic is unknown and the team need to establish what they do not know thus what must be learnt.

7.4.5 Typical Sequences

The analysis of the brainstorming phase shows the teams are all discussing what must be done in the future and during the reporting phase the group only refer to what has been done. There is little reflection on the process, discussion of where their research may be lacking and how to improve in the future (at least for the first round of data collection see chapter 5). It appears as individuals are relaying their research but receiving little input from the rest of the team. The information which is relayed is a given and is not challenged, it provides the ultimate conclusion when notes are taken for the 'summary' form.

For the year commencing 2017, the teams were having to conduct their independent research and create a case summary for two cases each week. These summaries were expected a couple of days after their reporting session of PBL. This prolonged the time spent on each case and meant the reporting phase was no longer when the team would finish. This meant the team were now discussing within their reporting PBL sessions the work which still had to be done rather than only what had previously been completed. This affected the way that students mentioned their learning resources, instead of being stated to validate the knowledge references were being shared so the rest of the team could access the same information. This shows a shift in behaviour because the analysis of data from the second round of collection indicates that the teams are now actively aiming to explain to one another what they had found and how this might be used in the future.

This implies that the reporting session during the second round of data collection was treated as an interim session where the teams have conducted some research but still spend time planning what is still to do before the submission of the summary notes. This has been visualised in fig. 7.1 to show the synchronous sessions (brainstorming and reporting), self-directed learning (research) and submissions which occurred during each round of data collection.

In the second round of data collection, there was not the same accountability for each team member as in the first session. This was seen from the lack of the contribution prompts and elaborations in the second round of data collection. Instead, the PBL groups were all contributing and working together rather than taking turns to have their say on one particular topic. It appears similar to brainstorming sessions but in a context where the team members have gained more knowledge in this area after having a week to complete research on the case.

7.4.6 Motivation

As previously mentioned the added submission for the academic year commencing 2017 (second round of data collection) was a summative assignment which held weight against the students' final grades for the module. This seemed to increase the incentive for the team to complete the summary to a good quality since it was going to be marked. This was a clear strategy identified in the transcripts from the second round of data collection. The team members would facilitate or direct these sessions prompting the group to focus on the content which is 'worth something' or on the mark scheme. This demonstrates that the motivation of 'grades' clearly had an impact on the working processes of teams during PBL.

Motivation as a strategy was only present for the second round of data collection, this does not assume that the students had no motivation during the first round of data collection. It just happened that once weighting was added to the submission this motivation and incentive was actively and explicitly used as a driver to the student's discussions. Whereas in the first round of data collection the student's motivation is more implicit since it is not stated openly in talk or used to prompt certain outcomes.

The insight into the team members motivation implies that the students have a strong performance orientation. Dweck & Leggett (1988) developed the performance orientation to explain how students motivation can affect their behaviour. The theory suggests that a student's goal is to achieve positive judgements whilst avoiding the negative or the possibility of making mistakes. Individuals are aiming to balance the effort with the expected reward, only willing to challenge themselves if the judgement is likely to be

positive. This idea is truly displayed when the teams orient to grades and marking schemes to help direct the team and make decisions. It shows the team balancing attention between the task and concern for performance outcomes, an approach which can lead to superficial processing (Nolen, 1988).

In this data, it is evident how the students are only focused on completing the submission to a certain standard and are not aiming to truly become expert with the content and skills (mastery orientation). This suggests that the students are not learning and deeply processing the content as would be expected in this active learning environment. Instead, the teams are legitimising minimal effort or reducing workload to ensure a good grade while not over challenging yourself.

There is one glimpse of a mastery orientation demonstrated during the second round of filming, previously presented in extract 6.12 on page 159. This shows the team conflicting on their goal, with some focused on only the incentive and others arguing that the cases are there to help the students learn and to help them in the future. The extract demonstrates the negotiation between team members who have opposing goal orientations, a promising observation since it shows some team members understand why PBL is being used and how it can help improve their learning.

Unfortunately, due to time constraints for this PhD project, the reporting phase of PBL could not be analysed for the third round of data collection. This might hold fruitful findings since the teams observed during the academic year commencing 2018 were still having to complete all the PBL cases in one semester but these had been condensed to only one per week. This class were also having to submit separate summary notes but in this academic year, they were no longer graded due to the large facilitator resource required to keep up with marking in the previous year. This means that the teams would still have the delayed submission date but without the extrinsic motivation of a summative grade. It is recommended that this analysis be completed as a form of future work.

7.5 Summary

This chapter has presented a thorough and detailed discussion of the findings from chapter 4, chapter 5 and chapter 6. This has then led into a comparative analysis where the major similarities and differences between these different analyses have been critically discussed.

The following chapter (8) presents the overall conclusions developed from this study, the implications for instructional practice and more recommendations for future research.

8 Conclusion

This chapter presents the overall conclusions of the thesis. There is a summary of the findings and explanation of how these are novel to the research field. There are also implications for instructional practice which have been informed by the findings of this thesis. The final part of this chapter provides recommendations for future research to continue the investigation into students' learning processes during problem-based learning.

8.1 Overview

The study aimed to gain an insight and understanding of students' learning processes during their first experience with PBL; to identify strategies which are used by team members to guide and manage the PBL process. This has been successfully investigated through analysis of naturalistic observations of students in PBL sessions. The thesis reports the analysis of 80 hours of naturalistic video data collected from students during their PBL sessions. The results of this research contribute to advancing the understanding of collaborative processes in problem-based learning. Hence these results complement and add to the current corpus of research focused on evaluating the outcome of PBL on a curricula scale.

The study has used a completely novel research design, combining the collection of video data and the use of qualitative content analysis. This is an original approach particularly in the field of engineering education. It has allowed the researcher to describe in detail the learning processes which occur during the students' first experience in PBL.

Interestingly the strategies identified in this work provide evidence to suggest that the

students are not working effectively as a group. There is an indication that the students are not conducting PBL sessions as they are designed or intended to be held when the teams are managing their group processes (i.e. “floating facilitator”) during their first experience with a PBL pedagogy.

As was expected from the literature the teams relied heavily on the scaffolding which was provided (e.g. PBL cycle and learning objective form) to help guide them through the stages in the PBL process. There were several ways this was observed for example through the use of the language from the PBL cycle and their continuous use of the case material to begin the discussions. This might have been primarily a result of their lack of experience with the PBL pedagogy and also dealing with unseen problems. In this context the students had been thrust into a learning setting which required them to take full responsibility for their learning, it is not surprising that they were highly dependent on the scaffolding and guidance they did receive. This was consistently demonstrated by the students in both the brainstorming and reporting phases of the PBL process since during the reporting phases of PBL the teams would use the prompts which were provided to conduct their conversations.

The study has also given evidence demonstrating how students negotiate collaborative tasks and primarily choose to use the ‘divide and conquer’ approach since this is perceived to be the most efficient strategy. This challenges the view that PBL is a pedagogy where students work to co-construct knowledge. The results of the study show that students orient to a cooperative approach more readily than knowledge co-construction.

One of the most promising results from this study happens to be seen in the variety and frequency of learning resources that are mentioned by team members. This suggests that the students are developing their self-regulation as evidenced through their ability to search and find relevant sources of information that help them acquire the knowledge to address the problem cases. This is rarely observed during the brainstorming phase of PBL, in this instance, the teams made use of the resources which are initially provided for them (e.g. the case material or tutor conversations).

The activation of academic previous knowledge has been identified in this analysis to show

when and how students relate new content to both the previous weeks and previous years' learning. There is however more elicitation of individual learners previous knowledge that was not captured during this analysis since it can not be objectively identified by the researcher. This study has indicated that PBL does require and prompt students to make connections between different knowledge domains.

In contrast to the use of learning resources, the activation of prior knowledge occurred more during the earlier phase of PBL when they have not researched the topic. They must call on their previous knowledge to address the unfamiliar case.

Another key finding from this work was how the team reporting sessions were changed from round one to round two of data collection. The prompts and elaborations which dominated the later stages of PBL during the first round of data collection gave further indication of a cooperative mode of learning where the teams were not truly co-constructing knowledge and merely relaying information they had found individually. This was different from the more active discussions which were had in the second round of data collection.

The only other major difference for the second round of data collection was how they would orient to their grades as a driving force for a specific plan of action. This was only explicitly seen when the teams were graded on the work they completed as a result of their PBL sessions. This might have been the result of introducing a summative submission for summary notes which were marked and held weight towards the final grade for the entire module.

Overall the study has highlighted the difficulty of adapting to problem-based learning after completing two years of a degree using 'lecture-based' instructional approaches. The results suggest that there needs to be greater preparation for students to be able to take full advantage of the PBL pedagogy.

8.2 Limitations

It is also important to consider the limitations of this study when reporting its results. The study has collected data from one particular PBL module where participants were all

students undertaking the same undergraduate engineering degree programme. This only represents learners studying in the Scottish context so the findings may not be relevant and applicable to other universities within the UK or internationally due to the variability of culture throughout educational institutions.

Similarly, the participants have only one semester where they are exposed to PBL for the first time in parallel with other "lecture-based" modules. Following the PBL the students then work together on a more complex group project. One concern is that this short time frame does not give the students enough time or practice for them to master the PBL process. This is particularly important in the context of this research since the PBL model uses a "floating facilitator" approach so there is more responsibility on the team to manage their learning process from the beginning.

The study and the research questions are framed to explore students processes during their first experience with problem-based learning. Despite the participants having already completed two years of their degree, they were all novice problem-solvers in the context of authentic settings. This could present bias in the observations since their behaviour could be different had the participants had more experience with PBL or collaborative problem-solving. This poses a significant constraint on the possibility to generalise these results.

Another perceived limitation about this work could be the small cohort of participants. However, this is to be expected when carrying out qualitative research, since the analysis used data from a naturalistic setting it is difficult to recruit a huge number of participants. The concern has been mitigated through collecting a large amount of data from these participants to attempt to provide a comprehensive and representative analysis of students' learning processes.

The qualitative content analysis requires the researcher to exercise judgement over data categorisation during coding. If not managed carefully this could affect the findings of the investigation. Since I am an advocate of a problem-based learning pedagogy I was aware that I might have held a bias towards the more promising strategies which were identified in the transcripts from PBL sessions. To ensure these perceived bias did not influence the

analytical process data sessions with additional researchers were conducted regularly to provide robustness and reliability of the coding scheme.

Notwithstanding these limitations, the study highlights how video recording data can be used to provide a novel contribution to the research on problem-based learning in engineering education and broaden the understanding of strategies used by students to manage the problem-based learning process.

8.3 Implications for Practice

The results of this study indicate that when implementing PBL with a 'floating facilitator' the students take prompts from the artefacts they are given instead of looking to a tutor to guide them. This means that there must be careful consideration of the scaffolding provided to the students, through the PBL cycle or the learning objective forms, to ensure they are being used as intended and are not misinterpreted.

As a practitioner it is known that students often choose to split the workload when working in a team, the tasks are delegated to individuals to be completed separately. This means the team are still aiming for a shared goal but they are not workings to collaboratively construct knowledge. This challenges the principle that PBL is a truly collaborative pedagogy. In this research, it was found that the introduction of a graded summary, a common document and goal for the whole team did discourage this behaviour seen by how the groups appeared to be more engaged and interested in the case content.

The findings of this study show just how complicated it can be to transition from a passive learning role, during lectures, to an active role, in PBL, where the responsibility of learning is with the students themselves. There needs to be the opportunity for preparation to help learners adapt to different methods of instruction. This is further discussed in section 8.4 since it will be useful to assess whether the teams' strategies change if the students have a better understanding of PBL and its requirements.

These results have led to some clear and actionable recommendations for instructors implementing PBL in their practice. These recommendations are outlined below, this list clearly states the issue or concern and gives practical solutions to address these

concerns.

1. Increased awareness of the PBL pedagogy
    (a) Throughout induction to the pedagogy, as a presentation or workshop to explain:
        i. How PBL works in practice?
        ii. Why PBL is used (using theory)?
    (b) Training opportunities to make clear different PBL roles for:
        i. Facilitators to understand their position to guide learning and help the students to find the answers themselves
        ii. Students to get to understand the active learning role required when working in a group during PBL
2. Detailed preparation for the PBL pedagogy
    (a) Training workshops to help students develop and practice collaborative learning competencies
    (b) Training workshops to help students develop facilitation of group processes and self-management
    (c) Earlier experience with PBL and other collaborative group working environment
        i. Implementing PBL at a lower level in the curriculum so that active learning and collaborative group work is more familiar
3. Appropriately designed scaffolding for the PBL process
    (a) Develop, test and evaluate the 'learning objective summary forms' to check they have the intended influence on the PBL process
4. Appropriately designed problem cases
    (a) Problems need to be open-ended, unfamiliar and challenging to allow for many different solutions

(b) It may be useful to conduct a pilot study, if possible, to test and further refine the problems and ensure they are understood as intended

5. Encouraging collaboration

(a) Aligning the activities and assessment with the objectives of group collaboration and group processes. These should include activities that provide the PBL team with a common goal to work towards and to keep individuals accountable at the same time.

These recommendations provide points for changes or amendments that can be easily implemented (such as clear inductions or training) and also some more involved approaches (the use of a pilot study to evaluate particular PBL artefacts or problem cases) that could help to optimise the introduction of PBL to a particular curriculum.

It was also found that during the two phases of PBL which were studied there are distinct strategies which correspond to the level of knowledge the students might have and also to the purpose of that particular session. It appears that despite articles having described the cycle of PBL, its stages do not appear aligned with particular synchronous PBL sessions. It is recommended that practitioners and researchers make it clear when specific stages of PBL need to be addressed.

In the majority of research which was reviewed and presented in this thesis, PBL is evaluated as a whole curriculum. PBL has many different facets and stages which occur at particular points in the cycle and each of these has particular requirements. The skills developed during the brainstorming phase of PBL are not the same as those for the reporting phase of PBL. Research needs to view these as separate aspects which sit underneath the heading of PBL but have significantly different purposes.

8.4 Recommendations for Future Research

Further research needs to be done to establish whether the strategies identified in this study would be similar if the participating students had more experience with PBL. This could be conducted through the same type of analysis but with experienced students from an institution where PBL is used not only in a single module or perhaps throughout their

degree programme as the core method of instruction.

There is also argument that it might be beneficial to conduct a longitudinal analysis to observe whether there is a change in behaviour between the initial introduction of PBL and when the students have become more familiar with the pedagogy, whether that happens to be over the course of a semester or even possibly throughout different years in a whole degree programme. This will require an appropriate learning setting.

Moreover, it is recommended that investigations take place to assess whether these same phenomena identified in this study occur in other higher education institutions within the UK as well as on an international scale. This could help to further understand the applicability of this research across different cultures.

Seeing that there have been some positive effects in the strategies identified following amendments in the assessment practices, it may also be interesting to gain insight on whether different preparation regarding the teamwork processes involved in PBL might influence the students' learning processes. This could be a detailed introduction to a similar module where students are adapting to PBL after having been taught using traditional 'lecture-based' approaches previously. It could also be by introducing students to PBL on their first day when they are not already accustomed to the passive approach to teaching and learning.

The idea of motivation and how this might affect students' learning processes have only been touched upon in this research. This could be interesting to research in more detail to gather more understanding of how elements of extrinsic or intrinsic motivation can influence the behaviour or engagement of students within PBL.

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A Appendix

A.1 Participant Information Sheet

Participant Information Sheet for CP-306 Process Design and Advanced IT class –tutorial meetings

Name of department: Chemical and Process Engineering
Title of the study: Professional skills development through collaborative tasks: student interactions and performance management

Introduction
My name is Robert McQuade and I am a PhD student in the Chemical and Process Engineering Department at the University of Strathclyde. I am conducting this research project, under the supervision of Dr. Esther Ventura-Medina and Dr Tony Anderson in collaboration with Dr Sally Wiggins and Seren Mabley, to investigate the processes of student learning within group interaction.

What is the purpose of this investigation?
The purpose of this investigation is to examine student group interaction and skills in order to provide practical guidance for students and staff in this learning environment.

Do you have to take part?
No, you do not have to take part. It is entirely your decision to take part in the investigation and your participation is voluntary. If, whilst participating in the recorded group sessions, you decide you want to withdraw from the study, you will be given the option to move to another (unrecorded) group, and recordings from the group you leave, which you appeared in, will be destroyed. Regardless of whether you take part in the study or not, your education will not be affected in any way.

What will you do in the project?
You will be asked to video-record your group meetings for the CP306 class (every week, two hours per meeting). You should act as you normally would while in the groups as the aim is to understand what normally happens in student group work. Each of these recorded sessions will take place in university buildings (room tbc).

Why have you been invited to take part?
You have been invited to take part as you are a student in CP306 *Process Design and Advanced IT*. Not all students need to take part: only four groups of students will be recorded for this project.

What are the potential risks to you in taking part?
There are no potential risks to you in taking part in the project.

What happens to the information in the project?
The information gathered via video recordings from you, your group and other participants will contribute to my PhD project, which is focused on understanding how students work in student groups and how learning takes place across the semesters. The data from the project will also be used for subsequent related projects by Drs Anderson, Ventura-Medina and Wiggins, but confidentiality will be maintained at all times. Pseudo-anonymity (where names are changed in order to make participants unidentifiable in transcripts) is assured to all participants in video transcripts. However, stills from video footage may be used in academic presentations or publications, and therefore your visual appearance will be visible in such pictures. Short video clips may also be used for

academic presentations, where it is important to understand the visual and verbal aspects of social interaction in group work. All recorded data will be securely stored on the university password-protected and encrypted university data storage facility, and any hard copies of data (e.g. video recordings) will be kept in a locked drawer in a locked office. The data will be kept for up to 5 years following the Good Practice Guidelines for the conduct of psychological research. Only the investigators involved in the project (myself, Dr Anderson, Dr Ventura-Medina and Dr Wiggins and Seren Mabley) will have access to the raw data.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

What happens next?
If you are happy to be involved in the project, please complete the consent form to confirm this.

If you no longer wish to be involved with the project, thank you for your attention thus far.

Once the project is completed, if you are interested, I will be happy to inform you of the findings by way of posting or emailing you my report.

Researcher Contact Details:
Robert McQuade
PhD student
Department of Chemical and Process Engineering
University of Strathclyde, James Weir Building
75 Montrose Street
Glasgow G1 1XJ
Email: robert.mcquade@strath.ac.uk

Chief Investigator details:
Dr Esther Ventura-Medina
Department of Chemical and Process Engineering
University of Strathclyde, James Weir Building
75 Montrose Street
Glasgow G1 1XJ
Email: esther.ventura-medina@strath.ac.uk

This investigation was granted ethical approval by the Departmental Ethics Committee (DEC).
If you have any questions/concerns, during or after the investigation, or wish to contact an independent person to whom any questions may be directed or further information may be sought from, please contact:

Convenor of the Ethics Committee
Department of Chemical and Process Engineering
University of Strathclyde
75 Montrose Street
Glasgow G1 1XJ
Email: contact-chemeng@strath.ac.uk

Consent Form for CP-306 Process Design and Advanced IT class

Name of department: Chemical and Process Engineering
Title of the study: Professional skills development through collaborative tasks: student interactions and performance management

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time up until the return of the video equipment, without having to give a reason and without any consequences.
- I understand that any information recorded in the investigation will remain confidential and no written information that identifies me will be made publicly available, though I understand that it is not possible to anonymise any audio or visual details on the video and that myself and the other group members may be recognised visually or orally.
- I consent to being a participant in the project.
- I consent to being video recorded as part of the project.
- I consent to video images or audio/video extracts being used in presentations or published material and for the purposes of teaching and/or research *(tick as appropriate)*. Yes☐ No☐
- I consent to still images from the video being used for academic presentations or published reports *(tick as appropriate)*. Yes☐ No☐

(PRINT NAME)	
Signature of Participant:	Date:

A.2 Data Management Plan

DMP title

Project Name My plan (University of Strathclyde)
Principal Investigator / **Researcher** Seren Mabley
Project Data Contact seren.mabley@strath.ac.uk, 07801966399
Institution University of Strathclyde

Administrative Data
Creator
Seren Mabley

Creator Department
Chemical and Process Engineering Department

ID
wlb16208

Co-investigator(s)
Dr Esther Ventura-Medina
Dr Anthony Anderson

Co-investigator(s) contact details
Dr Esther Ventura-Medina
Senior Lecturer, Chemical and Process Engineering
Telelphone Number: +44 (0) 141 574 5301
Email Address: esther.ventura-medina@strath.ac.uk
Dr Anthony Anderson
Vice Dean (Academic), Faculty of Humanities and Social Sciences
Telephone Number: +44 (0)141 548 2583
Email Address: tony.anderson@strath.ac.uk

Project title
Problem Solving - The Journey from Novice to Expert

Project Description
The proposed project addresses the challenge of the development of graduates professional skills within engineering, in particular problem-solving. The primary investigation being in the behavioural and performance characteristics of students when working in PBL activities.

Funder
John Anderson Research Award

Grant reference number

N/A

Project start date
03/10/16

Project end date
03/10/19

Date of first version
09/05/17

Date of last revision
19/05/17

Related policies

- University of Strathclyde Research Data Policy
- University of Strathclyde Research Data Deposit Policy
- University of Strathclyde Information Governance and Compliance
- University of Strathclyde Research Code of Practice
- University of Strathclyde Policy and Code of Practice for Post Graduate Research Programmes
- University of Strathclyde Information Security Policy
- RCUK Common Principles on Data Policy
- Good Practice Guidelines for the conduct of psychological research

Existing data
N/A

Data Collection

What data will be collected or created?

The data being collected includes

- Video recording of student group tutorials (PBL) and independent project meetings
- Students feedback forms completed during their group tutorials (PBL)
- Student reflections through written and oral communication for groups and individuals
- Student grades achieved for collaborative and individual assessments

How will the data be collected or created?

This data will be collected using the following techniques:

- Two cameras are set up at opposite sides of a small teaching or meeting room where students complete the PBL cases, these recordings are then transferred to a safe storage space.
- The feedback forms are required to be filled in by students during PBL for teaching purposes primarily, then scanned and stored safely so the researcher

can access them for analysis.
- The reflections are collected as an assessment for the CP306 Chemical Engineering Design module. Students are required to completed an individual and group reflective piece of writing once a semester. This can then be accessed by the researchers for analysis.

Documentation and Metadata

What documentation or metadata will accompany the data?

Each dataset will be accompanied by the appropriate metadata which will state what the data is, when it was collected and how, file type and file size. The documentation will further this by noting not only the objective aspects of the data but for it to be easily understandable by other researchers. This includes the naming conventions as well as how data was grouped and organised should this be forgotten or need to be passed on to new researchers.

There are different ways to provide metadata and documentation but for this project it will be completed for a collection level so it is provided for a collection of data rather than for each item separately.

Ethics and Legal Compliance

How will ethical issues relating to data be managed?

The main ethical issue for this project is that the data collected can be seen as sensitive. It requires consent from participants for data collection, storage and sharing.

This required an ethics application to be completed and amended according to the department committee requirements. Once this had been accepted recruitment began and then consent forms were signed.

Other ethical issues relate to the storage and security of the data, these are further discussed in the following section of this data management plan.

How will copyright and Intellectual property (IPR) issues be managed?

There are no copyright and Intellectual property issues. Regarding the access of data once the proejct is complete; according to the Good Practice Guidelines for the conduct of psychological research the raw data will be kept for 5 years this is explained to the participants.

Before this though there will be a comprehensive selection of data to decide what should be kept and what can be disposed.

Storage and Backup

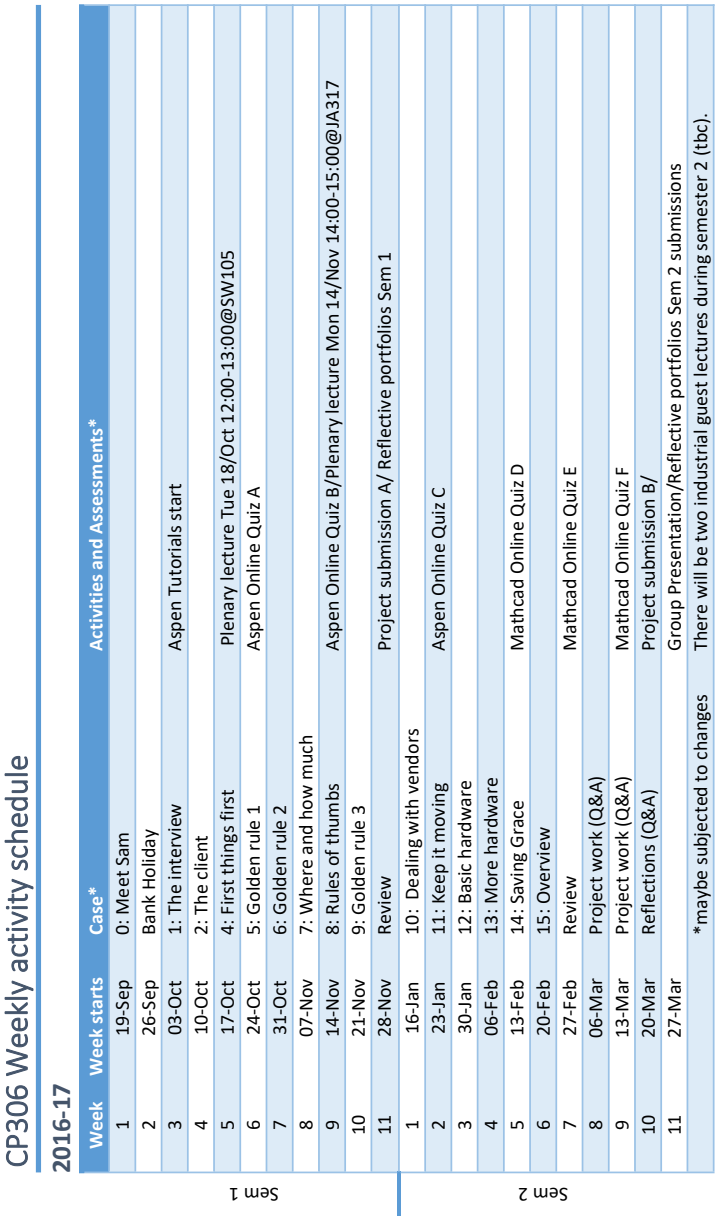
How will data be stored, backed up and shared during the research project?

All the data that is downloaded will be stored and saved on an encrypted university secure-cloud sharing service (I-Drive). A back-up copy will be created and saved to an encrypted external hard drive that is kept in a locked drawer in a locked office at the University.

How will access and security to data be managed during the research project?

A.3 Details for CP306 module organisation and schedule

A.3.1 Round 1: 2016-2017



CP306 Weekly activity schedule

2016-17

	Week	Week starts	Case*	Activities and Assessments*
Sem 1	1	19-Sep	0: Meet Sam	
	2	26-Sep	Bank Holiday	
	3	03-Oct	1: The interview	Aspen Tutorials start
	4	10-Oct	2: The client	
	5	17-Oct	4: First things first	Plenary lecture Tue 18/Oct 12:00-13:00@SW105
	6	24-Oct	5: Golden rule 1	Aspen Online Quiz A
	7	31-Oct	6: Golden rule 2	
	8	07-Nov	7: Where and how much	
	9	14-Nov	8: Rules of thumbs	Aspen Online Quiz B/Plenary lecture Mon 14/Nov 14:00-15:00@JA317
	10	21-Nov	9: Golden rule 3	
	11	28-Nov	Review	Project submission A/ Reflective portfolios Sem 1
Sem 2	1	16-Jan	10: Dealing with vendors	
	2	23-Jan	11: Keep it moving	Aspen Online Quiz C
	3	30-Jan	12: Basic hardware	
	4	06-Feb	13: More hardware	
	5	13-Feb	14: Saving Grace	Mathcad Online Quiz D
	6	20-Feb	15: Overview	
	7	27-Feb	Review	Mathcad Online Quiz E
	8	06-Mar	Project work (Q&A)	
	9	13-Mar	Project work (Q&A)	Mathcad Online Quiz F
	10	20-Mar	Reflections (Q&A)	Project submission B/
	11	27-Mar		Group Presentation/Reflective portfolios Sem 2 submissions
			*maybe subjected to changes	There will be two industrial guest lectures during semester 2 (tbc).

CP306 Weekly activity schedule

Activities Sem 1

Week	Monday 1	Monday 2	Tuesday	Friday	Notes Sub. Wed & Th.	Peer review sub. Fri. & Mon.
1	Case 1	Case 2	Lecture	Case 3		
2	No activities programmed					
3	Case 1 D	Case 4	Case 2 D	Case 5	Cases 1 & 2	
4	Case 3 D	Case 6	Case 4 D	Case 7	Cases 3 & 4	Cases 1 & 2
5	Case 5 D	Case 8	Case 6 D	Case 9 /Plenary	Cases 5 & 6	Cases 3 & 4
6	Case 7 D	Case 10	Case 8 D	Case 11	Cases 7 & 8	Cases 5 & 6
7	Case 9 D	Case 12	Case 10 D	Case 13	Cases 9 & 10	Cases 7 & 8
8	Case 11 D	Case 14	Case 12 D	Case 15	Cases 11 & 12	Cases 9 & 10
9	Case 13 D	Spare	Case 14 D	Spare	Cases 13 & 14	Cases 11 & 12
10	Case 15D	Plenary	Spare	Spare	Case 15	Cases 13, 14 &15
11	Revision					

2017 -18

Week	Wk starts	Case* (Monday)	Main topic	Case* (Friday)	Main topic	Activities and Assessments*
0	11-Sep	0: Meet Sam	Teamwork: difficult			
1	18-Sep	1: The interview	Process Design Basics: workflow and	2: Golden rule 3	Material and Energy balances -revisiting	Also this week Case 3: Basic Hardware (Hex design)
2	25-Sep	Bank Holiday				Submit: Team contract and Case 0 notes for trial.
3	02-Oct	4: The worth of a picture…	Revisiting diagrams	5: Keep it moving	Pumps and compressors	Submit: Case notes, Team contract and Team peer review
4	09-Oct	6: First things first	Physical properties and chemical databases	7: More hardware	VL/LL Separators design	Submit: Case notes, individual feedback and Team peer review
5	16-Oct	8: What way to go?	Process synthesis and route selection	9: Data and Specifications	Specification sheets	Plenary lecture. Submit: Case notes, individual feedback and Team peer review Case notes.
6	23-Oct	10: Rules of thumbs	Heuristics for PFD development	11: Saving Grace	Heat integration and pinch analysis	Submit: Case notes, individual feedback and Team peer review
7	30-Oct	12: Golden rule 1	Safety	13: Golden rule 2	Environment	Submit: Case notes, individual feedback and Team peer review
8	06-Nov	14: The client	Economic potential, Markets, Capacity,	15: Economics	Equipment costing and profitability	Submit: Case notes, individual feedback and Team peer review

A.3.3 Round 3: 2018-2019

CP306 Weekly activity schedule 2018-19

Key: D-Case discussion

2018-19 Sem 1

Semester 1

Week	Wk starts	Monday	Tuesday	Friday
0	10-Sep	Introduction, Teamwork/Belbin	Case 0: Fundamentals-M&E balances review/Teamwork	
1	17-Sep	Case 1: Basic Hardware	Case 0 D	
2	24-Sep	Bank holiday		
3	01-Oct	Case 2: Keep it moving	Case 1D	
4	08-Oct	Case 3: The basics of Process Design	Case 2D/Plenary	
5	15-Oct	Case 4: First things first -the data	Case 3D	Aspen
6	22-Oct	Case 5: Designing Chemical Processes	Case 4D	Aspen
7	29-Oct	Case 6: Equipment Data Specification shee	Case 5D	Aspen
8	05-Nov	Case 7: SHE in process design	Case 6D	Aspen Test
9	12-Nov	Case 8: Economic feasibility	Case 7D/Plenary	Spare Lab
10	19-Nov	Class Revision	Case 8D /Q&A	Design Test
11	26-Nov	Semester 1 Exam Preparation		

2018-19 Sem 2

Semester 2

Week	Wk starts	Day 1	Day 2	Support lectures
0		Project briefing		Safety
1		Project work (Q&A)	Aspen	
2		Project work (Q&A)	Aspen	
3		Project work (Q&A)	Aspen	Safety review
4		Group presentation, individual feedback	Aspen	
5		Project work (Q&A)	Aspen	
6		Project work (Q&A)	Aspen test	
7		Project work (Q&A)		
8		Project work (Q&A)		
9		Project work (Q&A)		
10		Project submission		
11				

A.4 Example learning outcome and summary forms

A.4.1 Round 1: 2016-2017

CP306 – Process Design evm-v2.stud

Group's Learning Objectives Form

Case Number: _____ **Date**_____

Group Number: _____

Group members present:

Issues identified (through brainstorming and categorization):

Description of the problem at hand (in brief, what is the problem at hand?):

Learning Objectives (LOs) identified (what do we need to learn in order to answer/solve the problem/issues identified?):

Research responsibilities (what are the topics that we need to investigate and, who is going to do it?):

Group's Discussion and Reflection Form

Date: _____ **Case:** _____

Group members present:

Summary (What did we learn?):

Reflections (how did we work as a team?, what did we do well? what could we improve upon?, what did we find difficult in this case?):

A.4.2 Round 2/3: 2017-2019

Team's Learning Objectives Form

Case Number: _____ **Date**_____

Team Number: _____

Team members present:

Description of the problem at hand (in brief, what is the problem at hand?):

Learning Objectives (LOs) identified (what do we need to learn in order to answer/solve the problem/issues identified?):

What research are we going to carry out (what are the topics that we need to investigate):

A.5 Case 5: Safety Considerations 2016-2017

CP306- Process Design evm-v.stud.

Case 5: Golden rule No. 1

Pat, a Senior Process Design Engineer, meets Sam in the coffee room. Sam is looking over a couple of the BFDs that have been drafted for the Ammonia Plant.

Pat: −G'day! I see that the team is already bouncing ideas for different processes. Have you done the HAZID yet?

Sam: −Not yet, we got the materials data. We have a meeting next week and we must have the preliminary HAZID...Safety checklist ready by then.

Pat: −No worries then, but it is also the time to start looking at the first step in plant safety. Pat's coffee is almost ready.

Sam: − err...of course! safe design!

Pat: − Remember, the mission is to make sure no-one gets killed because of the design. Safety above all!

Remember that you are in Sam's team!

A.6 Case 2: Material and Energy Balances 2017-2018

CP306- Process Design evm-v.stud.

Case 2: The fundamentals...

Inbox

From:les@kul-engineering.com
CC:lee@kul-engineering.com

Subject: Project CD-7709553-2017 -Everything must be balanced....

Dear team

Time to check some calculations. You need to check the values for mass flowrates and compositions on the attached Process Flow Diagram (PFD) for the Acetic Acid project before we go into the Basic Engineering Design stage. Team B (led by Lee, copied here) who produced this PFD will need your calculations with highlighted required changes as well as equations used described in general terms.

Below is the latest information about the process as the current version of the PFD.

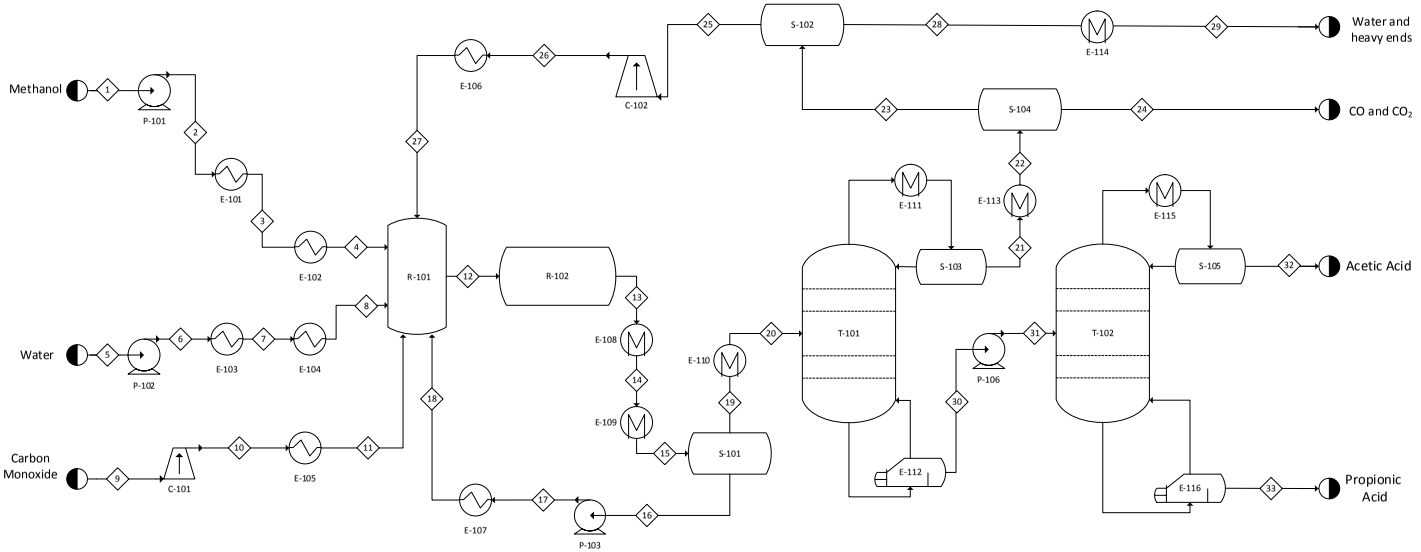
Les

Process Engineer
Conceptual Engineering Department | KUL Engineering

++

Production rate	100kton per annum
Reactions	
R1	Methanol + CO → Acetic acid
R2	Acetic Acid + Methanol → Methyl Acetate + H_2O
R3	Methyl Acetate → Propiaonic Acid
R4	CO + H_2O → H_2 + CO_2
Overall conversion of methanol	99%
Methanol conversion in R-101	75%
Methanol conversion R-102	96%
Water feed	5% w/w in R-101 inlet
Methyl Acetate	21.0% w/w in R-101 outlet
Separator S-101 target	Recovery unit for catalyst
Column T-101 separation efficiency	89.5%
Column T-102 separation efficiency	90%
Other Separators efficiency	100%
Note 1:	Water produced in R2 assumed to be unreactive in R4
Note 2:	For unknown conversions stoichiometric ratios assumed

P-101 Feed Pump
P-102 Feed Pump
E-102 Secondary Heater
E-104 Secondary Heater
R-101 Jet Stirred Reactor
E-107 Catalyst Recycle Heater
P-103 Catalyst Recycle pump
C-102 Methanol Recovery Compressor
S-102 Water Separator
P-106 Separator Feed Pump
E-109 Cooler
P-107 Distillation Feed Pump
E-112 Reboiler
T-102 Purifying Distillation Column
E-113 Condenser
E-115 Cooler
S-105 Reflux Drum and Product Separator
C-101 Feed Compressor
E-101 Feed Primary Heater
E-103 Primary Heater
E-105 Feed Heater
E-106 Methanol Recycle Heater
R-102 Plug Flow Reactor
E-108 Cooler
S-101 Flash Tank
T-101 Light Ends Distillation Column
E-108 Cooler
S-103 Reflux Drum
E-110 Cooler
S-104 Carbon Gas Separator
E-114 Cooler
E-116 Reboiler



Stream number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Temperature °C	25.00	25.00	100.00	180.00	25.00	25.00	90.00	180.00	25.00	25.00	180.00	180.00	180.00	130.00	80.00	146.75	146.75	180.00	146.75	98.00	94.30	50.00	62.00	62.00	80.00	80.00	180.00	80.00	40.00	131.00	131.00	131.00	131.00
Pressure bar	1.00	27.80	27.80	27.80	1.00	27.80	27.80	27.80	1.00	27.80	27.80	27.80	27.80	12.15	3.50	3.50	27.80	27.80	3.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	27.80	27.80	1.50	1.50	1.00	1.50	1.50	1.50
Flowrate kg/hr	10878.13	10878.13	10878.13	10878.13	973.48	973.48	973.48	973.48	8493.21	8493.21	8493.21	20450.31	20450.31	20450.31	20450.31	990.06	990.06	990.06	19460.25	19460.25	6209.44	6209.44	2389.03	3820.41	98.24	98.24	98.24	2290.79	2290.79	13250.81	13250.81	11472.21	1778.59
composition / mass																																	
Acetic Acid	0	0	0	0	0	0	0	0	0	0	0	0.5248	0.6930	0.6930	0.6930	0	0	0	0.7283	0.7283	0.2396	0.2396	0.6229	0	0	0	0	0.6496	0.6496	0.9572	0.9572	0.9951	0.7131
Propionic Acid	0	0	0	0	0	0	0	0	0	0	0	0.0004	0.0007	0.0007	0.0007	0	0	0	0.0008	0.0008	0.0002	0.0002	0.0006	0	0	0	0	0.0007	0.0007	0.0010	0.0010	0.0001	0.0067
Carbon Monoxide	0	0	0	0	0	0	0	0	1	1	1	0.1148	0.0189	0.0189	0.0189	0	0	0	0.0198	0.0198	0.0556	0.0556	0.0000	0.0903	0	0	0	0	0	0.0031	0.0031	0.0004	0.0205
Carbon Dioxide	0	0	0	0	0	0	0	0	0	0	0	0.0030	0.0039	0.0039	0.0039	0	0	0	0.0041	0.0041	0.0115	0.0115	0.0000	0.0187	0	0	0	0	0	0.0006	0.0006	0.0001	0.0042
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0002	0.0002	0.0002	0	0	0	0.0460	0.0460	0.0005	0.0005	0.0000	0.0008	0	0	0	0	0	0	0	0	0.0002
Water	0	0	0	0	1	1	1	1	0	0	0	0.0808	0.0914	0.0914	0.0914	0.9832	0.9832	0.9832	0.0002	0.0002	0.1290	0.1290	0.3354	0.0000	0	0	0	0.3497	0.3497	0.0071	0.0071	0.0008	0.0476
Methanol	1	1	1	1	0	0	0	0	0	0	0	0.1341	0.0054	0.0054	0.0054	0	0	0	0.0056	0.0056	0.0158	0.0158	0.0411	0.0000	1	1	1	0	0	0.0009	0.0009	0.0001	0.0058
Methyl Acetate	0	0	0	0	0	0	0	0	0	0	0	0.1413	0.1858	0.1858	0.1858	0	0	0	0.1953	0.1953	0.5477	0.5477	0.0000	0.8901	0	0	0	0	0	0.0301	0.0301	0.0035	0.2019
Catalyst	0	0	0	0	0	0	0	0	0	0	0	0.0008	0.0008	0.0008	0.0008	0.0168	0.0168	0.0168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

KUL Engineering		
Acetic Acid Production Plant		
Project ID 7709553-2017		
Overall Process	Drawn By:	JJ
Flow Diagram	Checked By:	
Base Case: 100000 ton p.a.		
100% Capacity, Normal Operation		
Drawing No	Sheet	Revision
PFD 1	1	4

A.7 Summary Marking Scheme 2017-2018

PROBLEM-BASED LEARNING CASE NOTES

MARKING CRITERIA

	Grade/10
Clarity and presentation To what level: • The information has been presented in a clear manner with a logical structure, flow and coherence. • There is a clear link between the problem definition, learning objectives and the content of the notes. • The notes are well written with good grammar.	
References To what level: • The references are listed using appropriate referencing standards (Harvard or Vancouver (numbers)). • The references listed appear within the content of the notes.	
Quality of notes To what level: • The notes contain information that has been clearly selected for relevance to the topic. • The notes contain, or make adequate references to, relevant examples and applications. • There is clear indication of how the content can be used or has been used in the solution of the defined problem. • There is clear demonstration of analysis and generalisation of the ideas as to make them useful in more general cases.	
Reflections To what level: • The team has shown reflection of their processes and the way the handle the learning process.	