"I'm lost" - A qualitative analysis of student teams' strategies during their first experience in problem-based learning.

Seren Mabley [a], Esther Ventura-Medina[a] and Anthony Anderson[b]

[a]Chemical and Process Engineering, University of Strathclyde; [b]Psychological Sciences and Health, University of Strathclyde

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ABSTRACT
Future global challenges that engineering graduates face have placed demands on engineering education and how graduates develop competency in collaborative problem-solving. Such demand has seen an increase in the use of pedagogies like problem-based learning (PBL) that provide opportunities for developing collaborative problem-solving skills. PBL has been well studied however there is still much to understand about 'how' students solve problems collaboratively in PBL settings. This work investigates the processes taking place when students set out to solve problems in a group. Naturalistic data from video recordings of participants in chemical process design PBL sessions is used. Participants conversations were transcribed and their language analysed using qualitative content analysis to provide a description of 'what' strategies students use. The findings indicate that students tend to adhere to relatively rigid structures and minimize effort when tackling unfamiliar ill-defined problems. Additionally, students appear to struggle making connections between knowledge domains.

KEYWORDS
problem-based learning; problem-solving; qualitative content analysis; teams; student strategies

1. Introduction

As the world faces the challenges around resource depletion, increasing population and higher living standards engineering professionals face the difficult task of providing solutions to the current and future world problems in order to ensure social and economic growth in a sustainable manner (Davidson et al. 2010). In the 2017 global university employability ranking problem-solving and collaboration were identified by over 80% of respondents as two of the key qualities graduates need (Baker 2017). This is not surprising perhaps in light of the fact that engineering graduates have to be able to face the ever changing demands of current workplaces. Hence, the ability for engineers to work as a team to deliver viable solutions in the short and longer term to the local and global problems would be contingent on the manner in which they would have developed these skills. The need for engineers to be able to face such challenges has instigated important changes in the engineering education curriculum and in particular, in the skills that are required of an engineering graduate to operate in such fast-paced environments.

CONTACT Seren Mabley Email: seren.mabley@strath.ac.uk

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

Problem-based learning (PBL) is a student-centred pedagogy which uses ill-structured problems in a real context to trigger the learning of fundamental concepts while developing professional skills from working in small groups (Duch, Groh, and Allen 2001; Vos and de Graaff 2004; Davidson and Major 2014). Many of the investigations into PBL within engineering give evidence to suggest that this more active learning method does help to improve students' grades when compared with traditional didactic approaches (e.g. Dalsgaard and Godsk (2007) McParland, Noble, and Livingston (2004); Woods et al. (1997)). Few studies on PBL have looked into improvements of professional skills accrued, and when they do it is done by looking at either products of learning (Warnock and Mohammadi-Aragh 2015) or through self-reporting questionnaires where students assess their own improvement in specific skills (Erdogan and Senemoglu 2014; Helmi, Mohd-Yusof, and Phang 2016). Effectiveness of PBL measured mostly on the basis of students' performance on tasks do not directly give any insight into the processes by which PBL can help students develop these skills. Imafuku and Bridges (2016) and Dolmans et al. (2005) suggest that these processes and interactions are something that needs to be further investigated. In general, there is still much to learn about group processes and collaborative work in educational contexts (Hammar Chiriac 2008; Faidley et al. 2000; Almajed et al. 2016). In the context of PBL, understanding what takes place when students are engaged in these activities within the classroom can provide an insight into the question of 'how' PBL can help to develop skills such as problem-solving through teamwork and in turn inform teaching practice. However, 'what' actually takes place during PBL sessions and 'how' students manage their learning process in an engineering PBL setting is not well known yet.

This work studies how engineering students, new to PBL, participate in the learning process and explores the strategies they use while 'doing' problem-solving during PBL sessions. In particular the work presented here focuses on the early stages of the PBL cycle when case analysis and problem definition take place.

As the study focuses primarily on 'what' actually happens instead of what is expected to happen from the perspective of instructional design the research study is designed using a qualitative approach based on naturalistic data. This approach enables the authors to gain an understanding on 'how' the PBL pedagogy might develop learners' skills, specifically problem-solving. The data is from participants in a Chemical Process Design module, at a Scottish University. The paper initially presents the conceptual framework and the background literature and follows onto a detailed description of the research methodology, results and an in-depth analysis leading to conclusions including the implications of these findings in future research and instructional practice.

2. Conceptual framework and background literature

PBL is a pedagogy guided by instructional principles that are grounded in a constructivist view of learning (Savery and Duffy 1995). The constructivist view of learning contends that each learners' knowledge is unique and is built up from their own individualised experiences across situations; therefore knowledge cannot be detached from the context in which it is acquired (Ertmer and Newby 2013). Knowledge is based on how the individual learner connects the new information and environment to previous experiences. This theoretical position claims that what is learned is not 'what the learner sees' in some objective sense, but it is 'what the learner thinks they see', and corresponds to an internal representation or interpretation of the information they were presented with (Svinicki 2010). Social constructivism originates from Vygotsky's sociocultural theory (Vygotsky 1980), another branch of constructivism which focuses on the concept that learning is influenced by the social environment (e.g. observations and also interactions) and as such learning is promoted by collaboration with peers. Barkley, Major, and Cross (2014) also emphasise the importance of collaborative group learning because knowledge is constructed through interactions, when a group reach consensus and create shared understanding.

However, it is recognised that the successful transfer of knowledge to unfamiliar domains requires to consider the context (situation) in which learning takes place. Situated learning (or situated cognition theory), based on constructivism, considers that learning is also dependent on interactions between a person and elements of the situation in which they act; that is, cognitive processes are not only happening in the mind but are also prompted and in some cases assisted by elements of the environment (Suchman 1987; Robbins, Aydede et al. 2009). Situated cognition has several parallels with social constructivism but it has specific implications on instructional environments, in particular that cognitive processes are anchored in activities and their context as well as the culture in which they were first learnt (Brown, Collins, and Duguid 1989). This underscores how important it is that the learning context is related to its application, to ensure transferability between the context in which something is learned and the context in which it has to be applied. This is quite important in the context of problem solving as the aim is that of professional enculturation (Brown, Collins, and Duguid 1989).

Both social constructivism and situated learning provide guiding principles which can serve for instruction and environment design in learning. However, in order to make instructional practice effective it is necessary that these elements (i.e. theoretical principles, instructional design and learning environment) are connected. Biggs (2014) established the notion of 'constructive alignment' in which the instruction, objectives and assessment of learning must all be focused on the same outcome so that learning and its application in practice is not hindered by its context. This notion of constructive alignment strengthens the argument for instruction to be designed realistically and with reference to a particular context, to close the gap between when learning occurs and when it might need to be applied.

Authentic and active pedagogies require the use of constructivist learning environments, which are completely student-centred. This type of learning environments are very different in their design and delivery to more traditional settings and instructional models such as lecture-based and are therefore somewhat controversial to implement (Prince 2004). Different to the 'didactic learning environment' in 'constructivist classrooms' the opinions of learners are actively sought out and listened to, the content is based on overriding concepts and the assessment

aligns closely with the teaching (Brooks and Brooks 1999). Likewise in constructivist learning environments collaborative techniques are included so that learners can work with peers, as it is understood from this framework that learning is not only affected by previous experience but through their social interactions.

2.1. *Problem-based learning*

As discussed earlier, PBL is a pedagogy established on the principles of social constructivism. In PBL students work collaboratively to learn from solving ill-structured and unfamiliar problems and reflecting on the experience (Hmelo-Silver 2004). It is an active authentic pedagogy which requires students to work autonomously and take a large amount of responsibility for their own learning (Prince and Felder 2006). It situates learning, putting it into a realistic context so that the learning is meaningful and valuable for working life. The use of realistic contexts is known to improve students' motivation; if they believe a task has value they are more likely to engage with it (Svinicki 2004). As an instructional model PBL can be implemented in a variety of ways yielding different instructional models guided by the purpose of learning. The PBL model used in the learning setting under study here may be closest related to that defined by Savin-Baden (2000) as "PBL for Professional Action". This model of PBL focuses on knowledge for application, learning skills for the workplace and uses real-life problems. It is attempting to situate the learning in context that resembles as closely as possible to the types of context in which it will most likely be applied in practice. This was first pioneered in engineering education by Woods (1996) at McMaster University. Several studies in the context of engineering suggest that the difference between workplace and classroom problems is quite clear, even to students themselves (McNeill et al. 2016) therefore using principles of situated learning in instructional design is of particular importance in engineering education. Therefore this model of PBL (for Professional Action) as an active student-centred pedagogy, that uses realistic problems in the context of workplace practice, can narrow this gap between classroom and practical application while giving undergraduate students more experience with open-ended problems.

Additionally, PBL has been identified as a pedagogy which can help to foster professional skills, including problem-solving and teamwork, and give opportunity for these to be put into practice (Warnock and Mohammadi-Aragh 2015). It has been thoroughly researched, and there is evidence suggesting that it can create a more effective learning environment. For example, it has been shown to improve students' performance in final assessments (Hillman 2003; McParland, Noble, and Livingston 2004; Mills and Treagust 2003; Wood 2004). Research into PBL has focused mainly on analysing the difference in undergraduates' grades following a module composed of either a traditional 'chalk and talk' or a problem-based learning pedagogical approach (McParland, Noble, and Livingston 2004; Woods et al. 1997). When the research only focuses on the products of learning - reports, exams and grades - it is essentially ignoring the concept of PBL that poses knowledge acquisition as a process (Imafuku and Bridges 2016).

2.2. *Problem-Solving Processes in PBL*

PBL is driven by a process of inquiry, the need to solve a problem or answer a question. Problem-solving can be described as the process of reaching a desired goal when the

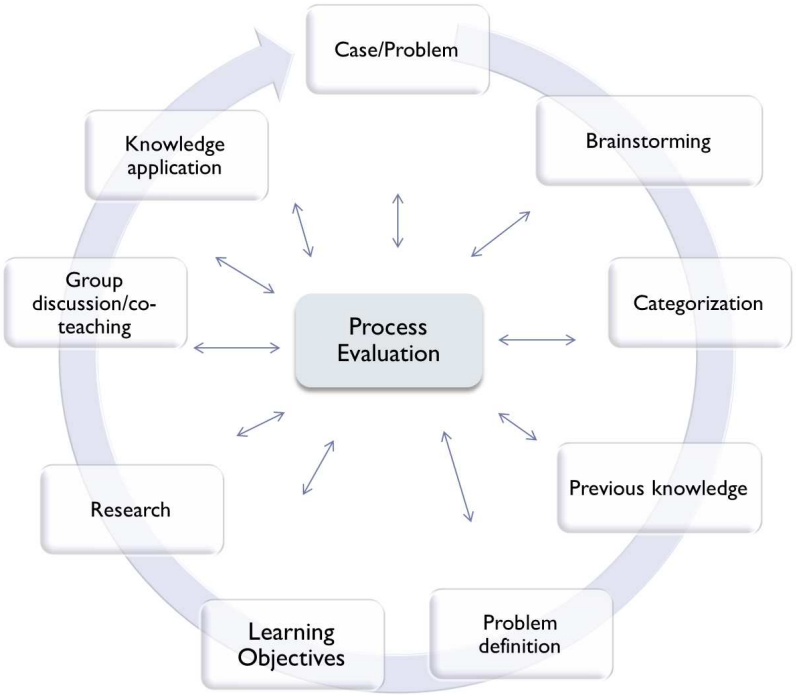


Figure 1.: PBL cycle as given to participants before and during their PBL sessions. This PBL cycle uses sub-processes identified as keywords to provide an anchoring structure for students as they encounter PBL for the first time.

route to that goal is unknown and unfamiliar (Martinez 1998). Being competent and confident with this process is described as having skill in problem-solving and as mentioned in the introduction it is not only expected but also required of all engineers. Additionally, it is often expected that graduates will become competent problem solvers while working collaboratively in a team. PBL provides the opportunity for the students to practice and hopefully perfect their collaborative problem-solving skill. This study focuses on elucidating the learning processes that take place while students new to PBL work collaboratively to solve problems.

As a learner the problem-solving process can initially be quite overwhelming so it is important to have a strategy. Figure 1 shows a visualisation of the PBL cycle used in this study to help scaffold the students processes in PBL. It has been adapted from the PBL cycle as developed by Hmelo-Silver (2004), who considers problem-based learning as a cycle made up of different sub-processes which facilitators may use to guide student (especially those new to this way of learning).

In this model the cycle begins with a new case prompting the team to analyse this case and identify the problem, generate hypotheses and further identify knowledge gaps. This leads to the formulation of the learning issues or objectives at the end of the first group PBL session. The students then research these learning objectives during their own independent learning and this new knowledge can then be relayed to the team in their final PBL session when they discuss their findings, co-teach and construct common knowledge. Reflection is a continual aspect of this PBL cycle where the teams evaluate their own process at all stages: early case definition, independent research and final group discussion. This is similar to the strategy developed by Woods (2000), who

also included processes related to promoting the engagement and motivation necessary for collaborative problem-solving.

The processes within this PBL cycle are what we, as researchers and instructors, assume will help students progress in their problem-based learning sessions. They are however not necessarily a true account of what occurs when learners take part in collaborative problem-solving. The authors' interest lies in understanding what actually happens during collaborative problem-solving so that the process can be described and their strategies identified. We are investigating 'how' students make use of conversational strategies when working in a problem-based learning environment to solve problems collaboratively.

2.3. *Research Questions*

Following on from the discussion of the background literature, it is noticed that there are too few studies which examine the naturalistic learning processes of engineering students when working in groups during PBL. That is why the authors have made the decision to focus this study on describing the complex learning processes that occur when students collaborate within a PBL environment as seen or identified through the language in their conversations. This is particularly important when the learners are not familiar with student-centred and authentic pedagogies such as PBL. The objective of the work is to find how the participants manage this active learning process collaboratively.

To this purpose the specific research question that the study addresses is: What strategies do students use throughout the initial stages of PBL (from case/problem to learning objectives as seen in Figure 1) during their first experience with a PBL pedagogy?

3. Research Design

This section of the article explains in more detail the theoretical framework which has informed the design of the research and provides support for the choice of the analytical method selected. It also describes how the participants' strategies during collaborative problem-solving were studied by examining learners' naturalistic talk in action within the learning environment and presents details of the data collection.

The research paradigm which has informed the research design for this paper is that of social constructivism; the belief that individuals create unique meanings of their own experience and these are different for every person (Cohen, Manion, and Morrison 2018; Creswell 2014). The implication this has on research design is defined by (Schwandt 1994);

> *The inquirer must elucidate the process of meaning construction and clarify what and how meanings are embodied in the language and actions of social actors.*

Therefore social constructivist researchers are aiming to develop a pattern of meaning through investigating processes among individuals within a specific context. This is in line with the authors' own conceptual position on learning theory as discussed in section 2. Our position, and the research question at hand, have led to a purely qualitative and naturalistic approach to the research since this work looks at describing what truly happens in real and authentic situations from the perspective of the participants. Taking this stance is particularly appropriate to the research question

being asked given that it focuses on identifying the students' strategies as they are conveyed through conversations during PBL -something which could not be achieved using an experimental or quantitative methodology.

Imafuku and Bridges (2016) state that the field is in sore need of a different lens in which to examine PBL as a pedagogy - especially when investigating how it can help develop interpersonal skills.

Qualitative Content Analysis (QCA) has been used in this work as "it is a method for systematically describing the meaning of qualitative material" (Schreier 2012). QCA is used to describe and make meaning from textual data (Krippendorff 2012). It enables the authors to condense the data to a manageable amount in a systematic way, while always keeping the analytical focus in mind. This type of qualitative method can provide understanding of the processes which occur in these learning settings.

In this study there was a clear objective to identify and describe the strategies seen in the students' conversations during their first experience with the PBL pedagogy. This meant it was important to choose a methodology that would provide opportunity for these to be classified explicitly. QCA is used in this manner to understand phenomena only in regards to specific intentions unlike other qualitative methods that give a more holistic view of the data being studied (Schreier 2012).

To capture these details video recording of PBL sessions was used for data collection and the transcriptions of the students discussions in the PBL session were then analysed. Further details of these are included below in 3.3.

This is a novel approach to investigate processes in PBL although other qualitative methods (e.g. script analysis of think-aloud protocols, thematic analysis) have previously been used to understand individual processes during problem-solving tasks (Douglas et al. 2012; Jonassen, Strobel, and Lee 2006).

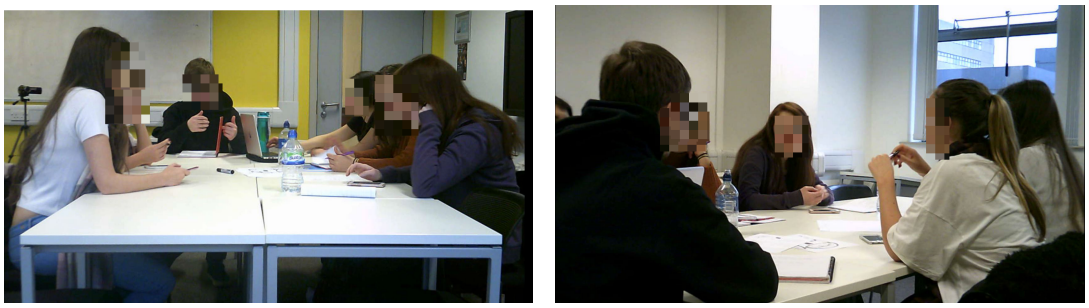
3.1. *Participants and Learning settings*

The participants who volunteered to take part in the research were 14 Chemical Engineering students, from a Scottish university, taking part in a core module covering Chemical Process Design. The study was granted Ethical approval by the Departmental Ethics Committee. The students were members of two groups of equal size as were the majority of the groups taking the same class. The class was allocated randomly into teams by the module leader, two of these groups then volunteered to take part in the study. Characteristics of these two groups can be seen in Table 1.

Table 1.: Characteristics of participant student groups by academic year and formation method.

Group	No. of Students	Academic Year	Cohort Size	Group Formation
1	7	2016-2017	136	Randomly allocated
2	7			

The participants in the two groups completed their group work in small teaching rooms away from the rest of the students studying this module however there was no other difference in terms of how they experienced the learning setting. Having the participant groups in separate rooms allowed collecting data through video recording with no audio interference from other groups around. Figure 2 shows an example of how the rooms were set up and the camera angles for a typical PBL session. For the transcription each student was given a pseudonym to ensure anonymity.



(a) Group 1 Camera 1 (b) Group 1 Camera 2

Figure 2.: Images to show the camera angles and room set up for video-recording (Group 1 has been captured as an example).

The module in this study takes place over two semesters in the third year of a Chemical Engineering programme, and it is a prerequisite for another module in the following year. The module is equivalent to 5 ECTS credits (10 UK credits) and the students were studying this in parallel to modules combining to another 25 ECTS credits. There is expectation that 5 ECTS corresponds to 100 total hours of study, in this case divided into two hours a week of PBL contact time and five hours a week of independent/private study. The module covers fundamentals of chemical process design while requiring some level of integration of prior knowledge such as process safety, thermodynamics and chemical engineering fundamentals. PBL is the sole pedagogy used in the delivery of this module with all content related to process design being covered with a series of PBL cases. It was the first time these third year undergraduate students had encountered the PBL pedagogy, having primarily been taught using traditional lecture-based methods. This gives a unique opportunity to study how students, new to PBL, tackle unfamiliar problems and how adept they can be solving problems as a group in this new environment.

The PBL delivery used in this specific study comprises of one group session (1-hour) when the team receive a new case, followed by individual independent research and a final session (1-hour) a week later to bring the research findings together. Students received a new case every week which they had to define and then research, each case followed on from the previous with a work-flow that mimics the design of a chemical process via a design project. The cases are centred around a student, Sam, who works as an intern in a Engineering, Procurement, Construction and Design company. The cases were devised to adhere to the principles of situated cognition and attempt to create an authentic environment that mimicked that of an engineer. The module is assessed mostly via an individual interview, reflective portfolios (individuals and group), peer-assessments and a collaborative group report which requires the students to apply all the knowledge acquired throughout the PBL sessions.

This module is the first instance where the students encounter the PBL pedagogy therefore at the beginning of the semester students are given an introduction to PBL. Figure 1 is the PBL cycle as given to students to provide a visualisation of the PBL process and stages involved in collaborative problem-solving. As mentioned earlier, it is an adaptation of the problem-based learning cycle from Hmelo-Silver (2004) and describes a number of sub-processes aiming to support students new to PBL. The PBL sessions use a 'floating facilitator' approach defined by Allen, Duch, and Groh (1996) as facilitators who are present intermittently and rotate between groups to support

the students when necessary.

Each group is also provided with a 'Group's Learning Objectives' form and a 'Group's Discussion and Reflection' form. The use of forms is based on work from Woods (2006) and helped to monitor the progress of the teams in relation to the learning outcomes of the module and provide them with feedback which was fundamental for the success of the 'floating facilitator' approach. Additionally, these forms are used as a 'whiteboard' (Hmelo-Silver 2004) for students to be able to articulate and record their thoughts throughout the session.

3.2. *Data collection*

Data was collected through the video recording of the two participating PBL groups who were taking part in the Chemical Process Design module. The teams conducted one PBL session each week which ran for two hours, one hour for consolidating independent research and one hour for analysing a new case. This was simultaneous for the whole class including the participants being video-recorded. The students took part in 14 PBL sessions but only 10 of these sessions were video recorded due to the study starting after the beginning of semester. These video-recordings were collected from October 2016 through to February 2017, within these months the PBL sessions and thus the video recordings are evenly distributed.

The video recording was completed using two cameras set up at either side of the room to capture two different angles, examples of these camera angles can be seen in Figure 2. A total of 20 hours of footage (including both angles) were analysed. This data corresponds to the first group session when the team are working through the initial stages of the PBL cycle (seen in Figure 1 as the stages from Case/Problem to Learning Objectives inclusive) when the teams received a new case. The video data recording corresponding to the later stages of the PBL cycle (i.e. after the research has been carried out) will be explored in a follow-up paper. The data reported on here gives an insight into how a group approaches a new problem in PBL when they are experiencing the pedagogy for the first time. The footage collected gave naturalistic data in order to address the research question and fitting with the constructivist framework. This decision to use video-recordings also has the advantage of providing opportunity for authors to go back to the data throughout the analysis unlike more traditional observations (Cohen 2011).

3.3. *Data analysis*

The data was analysed using qualitative content analysis (QCA) as mentioned earlier.

Verbatim transcription of the video recordings was completed using NVivo software following the procedure as described by Wiggins (2017). This is a basic method of transcription without indication of nuances or body language so that purely the spoken content can be analysed. Notes were made on each video to establish the on-topic conversations, this primary analysis is the first step towards condensing the dataset into a more manageable amount and focusing on the content which is pertinent for this study. Schreier (2012) comments that QCA "is done by classifying material as instances of the categories in a coding frame". Each category is comprised of a number of sub-catergories which have been assigned a code and these all form the coding frame. The NVivo software enables these transcriptions to be coded and compiled in one place.

Hence, the procedure of coding the data is the key aspect of QCA and it can be

approached in two different ways. It is described as directed when some categories have been predetermined or as conventional when the categories are derived solely from the data (Hsieh and Shannon 2005). The present research made use of the conventional approach since the strategies identified emerged from the data itself. It is however important, because the content is so rich and the talk diverse, to make a conscious effort to ensure that any emerging codes are relevant to the research question to be answered.

The QCA coding was first completed following the procedure outlined by Schreier (2012) on a portion of the data transcribed, the lead author completed this as a pilot phase to establish a coding frame which was further refined and the entire data set was coded using this. The authors also conducted several data sessions throughout this process, both prior to coding and to help refine the final scheme, to ensure reliability of the analysis. The final coding frame translates directly to the main strategies presented in Table 2 and these will be further discussed in section 4 of this paper.

4. Results and Discussion

The analysis on the data was completed through the use of QCA, several steps took place to ensure the rigour of the approach. The main findings of this study are the strategies which were categorised and each category assigned a code as defined in Table 2. Examples of each particular strategy has been provided through displaying extracts of conversation and identifying the content which is relevant to each. This set-up has been used because the quotes which have been coded need to be seen in the conversational context to be understood. The strategies were identified in the transcripts and then clustered to form two wider categories named Organisation and Resources. These indicate the two main techniques students use when managing collaborative problem-solving in their PBL sessions.

The objective of the analysis is to gain an insight into the processes which take place during students' first experience with the PBL pedagogy. This is so that more understanding can be gained about precisely 'how' undergraduate student groups approach problems when working collaboratively without direct instruction from the tutor. The results of the presented paper identify language used by the students that demonstrate particular techniques used to work through the PBL processes. They are techniques which have been identified through analysis of their talk and are discussed below.

4.1. *Organisation*

One main finding from the data was the focus the students held on making sure the session had some form of structure and the category Organisation specifically the codes, Language from the PBL cycle and Progressing Discussion indicate how they followed and maintained this structure.

4.1.1. Language from the PBL Cycle

It is understandable that third year students will have some difficulty adapting to the dramatic change of instruction; from being taught using lectures and assessed through examinations to the use of PBL. Therefore it is not surprising that the students often felt the need for some structure and rigidity to their PBL sessions. This suggests the

Table 2.: Definitions of strategies identified in the transcripts.

Code	Category Sub-category	Definition
	Organisation	
PBL	Language from the PBL Cycle	Reference to keywords from the PBL cycle (see Figure 1) as given to the students in their introductory lecture and in the feedback forms which they submit. This includes words such as problem, issue, brainstorm, learning outcome and learning objective.
PD	Progressing Discussion	Reference to 'getting back on track' or changing the conversation back to the case at hand. Explicit attempt to prompt the group to move on.
R	Roles	Reference to the allocation of designated roles; leader and notetaker, as expected from the tutor.
ER	Effort Regulation	Reference to simplicity or delegating/minimising workload.
	Resources	
CM	Case Material	Use of the words or phrases as seen in the new case material
T	Tutor	Use of the tutors as a resource, through mention of the written feedback or prior conversations.
APK	Academic Previous Knowledge	Reference to other modules within the same degree programme that students have either completed or are completing.

students struggle with the freedom they are given so they put in place a structure similar to that implemented by a tutor in more familiar instructional techniques such as previous lecture-based modules. This is demonstrated through the persistent use of keywords from the PBL cycle, seen in Figure 1, to describe steps within the problem solving process. For example we can see in Extract 1 line 1 Josh uses the word problems to start the conversation about the case. Woods (2000) suggests that using a structure can be useful because it can help overcome the initial panic when given an unfamiliar problem; it gives the learners an immediate task to do. The keywords are used by the participants to identify stages that need to be addressed and in time become a common language within a group. The students vocalise keywords from the PBL cycle to indicate at what stage they are currently at and there is an understanding of what is expected for these different stages. Thus prompting the team to work through the sub-processes involved in collaborative problem-solving as provided from the PBL Cycle (Figure 1).

However the concern about the use of this technique within PBL sessions is that it caused the participants to address PBL and therefore problem-solving as a linear or sequential process. Following the steps of the PBL cycle in such a manner meant that students did not revisit previous steps; moving on once each step was sufficiently completed. PBL is a cyclic and iterative process with the possibility of revisiting a prior step in order to refine the categorisation, problems formulation and definition of learning objectives. PBL should be uncertain and 'messy' (Lucas, Hanson, and Claxton 2014). By putting in place a rigid strategy the process becomes ordered, it

Extract 1.

			Code
1.	Josh:	problems then	PBL
2.	Katie:	whats a design basis sheet?	
3.	Josh:	mmm wheres that? at the bottom	
4.	Katie:	at the bottom yeah	
5.	Josh:	so 'this has to be accompanied by a calculation	
6.		sheet template for scaling up so you can	CM
7.		input the results in the design basis sheet' um	
8.	Hannah:	its just a sheet like summarising like	
9.	Ryan:	yeah	
10.	Josh:	it'll just summarise like what you need to	
11.		consider when your designing it I suppose	
12.	Katie:	oh right	
13.	Ryan:	yeah	
14.	Josh:	we could do that as a learning outcome research	PBL
15.		like what goes in a design basis basis sheet	

is not conducive with creative thinking which is necessary to succeed in collaborative problem-solving.

One key part of the PBL session is to formulate learning objectives; questions relevant to the case which need to be researched and answered in order to solve the problem. These learning objectives are seen as a milestone, an achievement to aim for and thus when mentioned in conversation it leads to some form of conclusion or decision. This stems from the structure of the PBL cycle being seen as a sequential process which they need to follow. As explained earlier Extract 1 shows how these keywords are used to begin discussion, but line 14 presents the opposite of this where this topic is concluded quickly by suggesting to create a learning objective (referred to as a "learning outcome"). This shows that the group is not taking part in critical discussion of the case. It appears they are more intent on completing the minimum of what is required of them, focusing solely on establishing an action plan to move forward but without investigating and determining the real meaning of the case. They are motivated by finding a solution rather than gaining a clear understanding of the task, this is a key characteristic of novice problem solvers as observed by Camacho and Good (1989).

4.1.2. Roles

Another topic which appears to help students organise and give order to their PBL sessions is that of the prescribed roles. As part of the group work in PBL the students were asked to produce a rota for a dedicated notetaker and discussion leader for each session. These roles give responsibility to individuals to either chair or take minutes during each session. Creating a rota should mean that everyone has to do this at least once; it is not always down to the same individuals. In the beginning of almost every session both groups take time to establish who is leading and taking notes for that case. This highlights these participants early on in the session and makes known to the team who is responsible for these roles. The students are easing themselves into the task by initially making it clear who should be taking each role, Extract 2 shows one instance where the team were negotiating the role assignment. In line 4 Molly asks "who's the note taker" she receives a quick reply when Linzi states in line 5 "I think it's me" then Annie joins the conversation in line 6 telling Molly "you can lead". This

is just one example of when the teams allocate the responsibility of these positions at the start of their PBL sessions.

Extract 2.

			Code
1.	Annie:	erm right have you read through the big case	PD
2.		yet	
3.	Sharon:	have you got the sheet	
4.	Molly:	who's the note taker again	R
5.	Linzi:	I think it's me	
6.	Annie:	you can lead *((to Molly))*	R
7.	Molly:	so what do you think	
8.		*((Inaudible talk and laughter))*	
9.	Annie:	seems to me like last week but with	APK
10.	Molly:	waste products and stuff	

The implied need for assigning roles could indicate who the team expect to guide the group through the problem-solving process and make final decisions, possibly viewing the leader as a substitute tutor who has responsibility for the progress of the team. Allocating roles early in a session sets a precedent for who should be doing what, if there is any reference to this later in the session it could be a sign of trouble that the role has not been sufficiently undertaken. This is never explicitly stated in this corpus of data indicating that this issue is either not encountered or is successfully managed by the team. An interesting difference between the two groups examined was that one consistently followed the rota developed at the start of the semester and the other group appeared to make a spontaneous decision based on who might have performed this role previously or from what they could remember, the latter being a much lengthier process. In one instance there are 8 role-related utterances coded within the space of fifty seconds. This led to a loose definition of the role causing the more dominant individuals to regularly take on the responsibilities of these roles.

4.1.3. Progressing Discussion

This section refers to instances when the group are pushed on by a member of the team without using the PBL cycle keywords. An example is shown in Extract 2 line 1, Annie is trying to move on the discussion when she says "erm right have you read through the big case yet". This was observed as a technique to start discussion and to change topic. It was regularly used to divert from off-topic talk and bring the group back on task. This suggests the problem-solving process is not moving forward and the group requires prompts to keep up the momentum and not become overwhelmed. Another example of this is seen later in Extract 6 in line 1 when Katie attempts to get the group back on track. It would be expected that this responsibility of keeping the group on track would lie with the leader of the discussion but utterances linked to this code often come from more dominant team members. This mode of facilitation in collaborative problem-solving has been described as 'prominent proactive' where the leader regularly has to step in to keep the group on track to make progress (Carmichael 2013). This strategy may be necessary in this context due to the absence of the tutor figure who would have this facilitating influence helping the group move forward and make progress in their problem-solving. In contrast groups that are familiar with problem-solving use more invisible facilitation where the discussion moves on naturally and does not require interference, this may be something which would have happened

Extract 3.

			Code
1.	Sharon:	it doesn't seem very much it seems like just	ER
2.		environment I've probably went and spoke too	
3.		soon	
4.	Laura:	if its environment and we don't do environment	
5.		until next semester	
6.	Sharon:	see in fairness Molly looking at environment	
7.		like this week I thought it kind of seemed like	
8.		common sense like don't have it near houses	
9.		let waste products get transported out of the	APK
10.		place that kind of stuff kind of like common	
11.		sense similar to safety last year	
12.	Laura:	yeah	
13.		(1.0)	
14.	Annie:	oh an effluent summary and a plan for	CM
15.		addressing potential environmental impacts	
16.	Molly:	yeah what is an effluent again (.) is that like	

if the students had more experience with the PBL pedagogy.

4.1.4. Effort Regulation

It was also found that students regularly orient to simplicity; they attempt to downplay the difficulty of a task. For example in Extract 3 line 1, Sharon says "it doesn't seem very much" indicating that the task might not be particularly challenging. This may be because she genuinely believes the task to be simple but it could be a strategy used to increase morale and self-efficacy of the group. By expressing that the work might not be challenging this could help the group believe they can solve the task meaning they are not defeated, it is easier for the team to manage and make progress. Martinez (1998) makes comment on this suggesting that playing down the complexity of a problem can help learners to take the initial step and not become overwhelmed by the overriding problem.

In Extract 3 line 1 it can be seen that by legitimising a lower workload, Sharon narrows the problem so that the group have less to consider in its solution. This same phenomenon is demonstrated throughout the PBL sessions and other examples can be seen later in Extract 5 (line 7) and Extract 6 (line 6). This is a concern which has been discussed by Biggs and Tang (2011), with increasing number of students, more learners who are less academically inclined are attending university. These students are not motivated in the same way as someone who is truly interested and passionate about the subject; they focus only on completing the minimum amount of work to gain the qualifications they need for a good job. This is in line with the work of Dweck and Leggett (1988) as reported by Svinicki (2010) regarding achievement goal orientation theory. These learners are balancing effort with value by taking a strategic approach to learning. For the team to make progress in PBL this strategy can be helpful in the short term as it makes it easier to address the problem at hand but it may be problematic in future because it limits the knowledge acquired to a specific concept and ignores the wider ideas.

Another instance which shows strategic management of the groups effort to complete a task is the concept of 'splitting work up' as seen later in Extract 5 line 1. The act of splitting up work occurs regularly at the end of PBL sessions, when the students have

established what they need to know and are putting in place a plan of action to go ahead with the necessary research. Through splitting up the research and delegating single topics to particular students they are significantly decreasing their individual workloads. The idea that they divide and conquer is one that the undergraduate students believe to be efficient. However it can lead to each student gaining only fragmented knowledge of the subject rather than a solid foundation, this is a concern regarding the implementation of PBL because engineering has a hierarchical structure (Perrenet, Bouhuijs, and Smits 2000). This notion is challenging PBL as a collaborative technique; the students are actively going against the expectations of this pedagogy by delegating work to be completed separately.

4.2. *Resources*

This section describes the use of resources that occurs during the PBL sessions as one of the main categories found. This is an important finding because to properly engage in PBL students need to draw upon all the available information that they can access. Effective use of resources demonstrates the self-regulation necessary to succeed in problem-solving. The extracts below show examples of when the students have taken the initiative to seek support from the case material, the tutor and their own previous academic knowledge during the problem-solving process. These happened to be the most prominent resources that the participants use at this initial stage of the PBL process.

4.2.1. Case Material

The repetition or reading aloud of the case material they have been given is another technique adopted by the students to begin discussion - more often observed at the start of PBL sessions. For example this can be seen earlier in Extract 1 in lines 5-7 where Josh quotes directly from the material they have been given. This is given to every student to read but repetition of words and phrases from the case helps emphasise the ideas. Similarly to the use of terminology related to the PBL cycle it is used as an initial turn; it instigates conversations which prompt questions and provides a platform for students to express opinions. It may also have the purpose to alert students to particular points in the case which one student believes are important and need to be highlighted. It means that the content is publicly acknowledged, articulating what may or may not have been read. It is almost as if the students are verbalising their own thought process, the first step in problem-solving that might be unconsciously done when working alone but needs to be vocalised when working in a group.

Although it is more prevalent at the start of a PBL session it is also used to strengthen a student's point during discussion. It is seen that when one participant appears to not agree or think differently to another they bring the conversation back to what was given to them. This is exhibited in Extract 4 in line 1 where Katie refers to what is on the sheet to further emphasise her point, in a way which presents it as not just her own opinion but that of their tutor. This gives promising evidence to show that the material is being actively used to trigger discussions however it does imply that students tend to target specific topics or words stated in the case and do not always consider the wider picture. The students stick with the idea they have first conceptualised rather than searching and evaluating alternatives. This phenomenon is something previously documented by Samuel and Jablokow (2010) and Valentine, Belski, and Hamilton (2017), who suggest this tendency is due to lack of practice

Extract 4.

			Code
1.	Katie:	and it says 'as we have already done the PFD'	CM
2.	Ryan:	mm unless its still talking in terms of like	APK
3.		the ammonia	
4.	Oliver:	oh yeah yeah	
5.	Katie:	have we done it for that ammonia one	APK
6.	Ryan:	don't know we did	
7.	Josh:	it'll be a PFD first	
8.	Ryan:	we did we did do it but	
9.	Josh:	do that first then got all this like line line	
10.		calculations like here like see erm on the	
11.		bottom of the PFD she *((the tutor))* told us you	T
12.		need all the streams and that I think this is	
13.		what that is basically	
13.	Ryan:	we've not got a PFD for this	
14.		*((inaudible talk))*	
15.	Katie:	oh the last case it said 'we are looking to	APK
16.		start the PFD development' so I think we might	
17.		have had to do that on the last case	

with creative problem solving. In the wider problem-solving literature it has also been noted that humans exhibit a *'keyhole view of the problem space'* and that failing to adequately explore alternatives is important in human error underlying accidents and disasters (Reason 1990, 38).

4.2.2. Tutor

Another resource which the students make use of in their sessions is relating back to something the tutor has said or commented on previously. This is either used to emphasise a point or as a way of the students relating the new material given to them to what their tutor has discussed previously. For example, in Extract 4 lines 9-11, Josh tries to clarify the task by relating it to a conversation with the tutor. This shows that the students are trying to form connections between the different channels of information they receive, and in particular the case material and the instructor. It is promising to see the students make progress through establishing familiarity or overlap in content because it prompts more discussion and might elicit ideas from other team members. However, one problem with this strategy is that they still rely on the tutor for some direction, suggesting that this learning is not wholly autonomous and students struggle to adapt to this active student-centred pedagogy. It appears the participants have a tendency to work with what the tutor has previously mentioned to them rather than formulating their own ideas.

4.2.3. Academic Previous Knowledge

Based on the conceptual framework of this study and following a review by Schmidt, Rotgans, and Yew (2011) it was hoped that students would relate the content of their PBL sessions to topics that they had previously studied or were in the process of studying. This connection to prior knowledge is how learning can occur, through constructing and re-constructing knowledge based on what one already knows. It was noticed that during the group PBL sessions this connection was verbalised. Earlier in Extract 3 lines 5-9 we see Sharon explicitly state that the content was similar to safety

last year, and this shows how she is connecting the new material to something she has previously studied and then explaining this to the team. This process often occurs during learning and knowledge acquisition but when working alone it would not be necessary to verbalise it. This occurs again in Extract 5 in line 9 and 10 Matt refers to "the fluid flow ones" something he remembers that he has done before. Although this is much more indirectly expressed it will still give an indication to the other group members of what he is linking back to.

Extract 5.

			Code
1.	Matt:	you can split it up in your (unclear) so you	
2.		can heat exchanger two people can do heat	ER
3.		exchanger for LO2 the one for ammonia and we'll	
4.		do the one for water	
4.	Katie:	mmhm	
5.	Josh:	calculations	
6.	Katie:	right so learning outcome 1	PBL
7.	Josh:	do we actually need to do these by hand	ER
8.		*((inaudible talk))*	
9.	Matt:	I can remember doing I can remember the fluid	
10.		flow ones for I can do the heat exchangers but	APK
11.		thats it and I wrote it out like 5 or 6 times	
12.		before I fully got it	

Making connections like this is a positive feature of the students' dialogues; however in most instances where this has been observed, it is not relating the current problem to those within previous modules, it is noting the relevance of previous cases that have been studied within the same module (i.e. the chemical process design module). One example of this is demonstrated earlier in Extract 2 in line 8 when Annie refers to "last week". It is useful for the students to make this connection because it shows that they understand how the cases lead on from one to another. However it shows a limited number of instances when the learners connect across areas of knowledge. This suggests they have a compartmentalised view of the module and believe it is not necessary for them to draw upon previous experiences and knowledge acquired in other situations. This is particularly problematic in relation to developing problem-solving skills.

Another inference made from this finding is that through situating learning in a specific context, students can get caught up with the minute details rather than focusing on the bigger picture (Bassok 1990). This was often a problem with the participants; the groups would understand that the cases were all linked, but they became rather distracted by the story and often the overriding message of the problem was overlooked. This point is clearly seen in Extract 6 where the group takes some time to discuss whether they need to focus purely on the ammonia process similarly to the previous cases. Josh's utterance in lines 10, 11 and 12 gives a very good example for this when he is asking about whether this case is carried forward. If they do narrow things down and focus on ammonia production it might then hinder their ability to transfer the content to other processes. This indicates that some students can get caught up with the 'superficial' aspects of a problem. This is a major difference between expert and novice problem solvers, experts find it much easier to recognise relevant fundamental concepts because they have more experience with a larger number of problems (Svinicki 2004).

Extract 6.

			Code
1.	Katie:	right lets get back on track guys	PD
2.	Matt:	yeah concentrate cause they've now got it on	
3.		camera	
4.	Katie:	so what do you think the problems are	PBL
5.	Hannah:	environment	
6.	Josh:	mm yeah	
7.	Katie:	just environment	ER
8.	Hannah:	yeah just like the damage you can do on it mm	
9.		like pollution fumes and other stuff on it	
10.	Josh:	so this case is this carr I think this is	
11.		carried forward so are we supposed to have	APK
12.		selected a process and just do it on that one	
13.	Matt:	yeah	
14.	Josh:	should we do it on LAC	
15.	Matt:	yeah	
16.	Ryan:	yeah so what um	
17.	Katie:	or is it maybe not more general like	
18.	Josh:	thats a good point actually	
19.	Hannah:	yeah	
20.	Katie:	remember in the last earlier stage she was	T
21.		like be general don't make it all	

5. Conclusions

5.1. *Summary of Findings*

This study aimed to provide a description of what takes place during collaborative problem-solving and in particular identify the strategies used by students new to PBL to manage their learning process in the first stages of PBL. The study has employed a novel approach in data gathering with the use of naturalistic video data which has allowed capturing through language the details of what takes place when students are 'doing' collaborative problem-solving.

A series of strategies used by students were identified after analysing, through qualitative content analysis, the verbatim transcriptions from 20 hours of video recording of PBL sessions.

The resulting descriptive framework, see Table 2, categorises the strategies used by students under the headings of Organisation and Resources. Each of the categories indicates strategic elements the students use in the learning process. The category of organisation considers four sub-categories including the use of language from the PBL cycle, attempts to progress discussion, assigning roles and regulating effort. The category of resources considers the use of case materials, support from the tutor and academic prior knowledge.

The data indicates that the participants spend a long time talking about how to organise their PBL sessions. The strategies progressing discussion and language from the PBL cycle are used to move the team forwards in their collaborative problem-solving effort. These may also include how a tutor or facilitator might behave had they been present in the PBL session. This suggests that the teams are heavily reliant on some form of facilitation and they struggle to work autonomously without guidance from a tutor. This is in line with Woods (2000) who reports using scaffolding and structure can provide the team with an immediate task so will help to start

the learning process and dispel any initial concerns when approaching an unfamiliar problem. This result is corroborated by how the students are focused on assigning role responsibilities for each session and could be attributed to the unfamiliarity of the PBL pedagogy.

Results from the category of resources indicate that, at least in this stage of the PBL cycle, students tend to refer to case materials and academic previous knowledge mostly drawn from this single chemical engineering design module. Data shows that in the majority of instances students manage to establish links between the different cases presented to them in this module but are not very adept to draw connections with information from further afield; previous or past knowledge or experiences. When previous work or experience were briefly recalled by one student it was rarely taken up by others and often just brushed aside.

It seems as if the students view the module as self-contained and independent from any other knowledge domain. Barrows (1996) talks of the importance of developing an integrated knowledge base, this is difficult to achieve when students continue to isolate the learning from specific modules. While collaborative problem-solving in PBL requires a more synoptic view of knowledge and it gives opportunity for this to be developed, we see that more time needs to be given before this is fully understood and appreciated by the students. Moreover, it is evident from the data analysis that students tend to rely on the tutor for direction and to an extent to justify other strategies used (e.g. effort regulation).

5.2. *Implications for PBL practice*

The results presented here illustrate that PBL does offer opportunity for students to develop their collaborative problem-solving skills when dealing with real-world problems. However, the findings of this paper support the idea that students find it difficult to adapt to a PBL pedagogy, and perhaps more so, after previously learning through traditional "lecture-based" instruction. This idea has been discussed as a major challenge for PBL implementation by Zin, Williams, and Sher (2017). For students to become comfortable with active participation and autonomous work the implementation of PBL into an engineering curriculum might need to be more systematic and global. This approach requires a concerted effort made by whole courses/departments/faculties if the need to prepare graduates to face the global challenges are to be met through the use of active pedagogies. By giving students more practice with an authentic student-centred pedagogy, such as PBL, they can harness its true potential and become expert in problem-solving. Still it remains to be seen whether the students working effectively and autonomously would result solely from a PBL-heavy curriculum without the need of further intervention.

The most striking finding is perhaps the persistent use of the PBL cycle language to identify processes which need to be completed. Providing the students with the PBL cycle is done to give them a starting point to help guide the students through their collaborative problem-solving. From the data and its analysis it is clear that the PBL cycle was also regularly used as a way to set milestones which needed to be achieved in the session. The use of the PBL cycle in this fashion indicates an adherence to a linear structure that initially helps the team to set the problem (as reported by (Woods 2000)), if rather narrowly, but that in the long term could be counter-productive as it would detract from elaboration and broader views. This indicates that careful consideration is required to provide the correct level of scaffolding for the students, to

give the guidance they need to work autonomously while also encouraging critical and meaningful discussions of the PBL task. This might mean adapting the PBL cycle and the group learning objective form or maintaining more regular discussions about the PBL process with the students involved.

5.3. *Limitations of the Study*

It is important to frame these findings considering the limitations of the study. This study has been carried out in a specific context where participants were all students undertaking an undergraduate engineering degree programme and also were new to the PBL pedagogy. Additionally, despite the fact that the participants were students in the third year of their degree they were all novice problem-solvers in the context of authentic settings. This could present a bias in the observations which could be different had the participants had more experience with PBL or collaborative problem-solving. This research has also only considered Scottish context so the findings may not be applicable to other places within the UK or in other countries due to the variability of culture in educational institutions. The study was also limited to a small cohort of participants but this is expected when carrying out qualitative research especially when collecting data from a naturalistic setting.

Notwithstanding these limitations, the study highlights how video recording data can be used to provide a novel contribution to the research work on problem-based learning and broaden our understanding in great detail of the processes involved in collaborative problem-solving.

Further research needs to be done to establish whether the behaviours and strategies identified in this work would be similar if the participating students had more experience with collaborative problem-solving or PBL. Moreover, future research could also investigate whether the same phenomena occur in other institutions within the UK as well as on an international scale.

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