Problem-based learning in Computing

A pedagogy for employability

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Introduction

While educators in the UK higher education (HE) face many challenges, one that has taken up a position on centre stage is the issue of graduate employability (Pegg et al. 2012). The language used by the funding council is clearly directive: “Embedding employability into the core of higher education will continue to be a key priority of Government, universities and colleges, and employers” (HEFCE 2011, p. 5).

However, the complex mix of attitudes, abilities, values, skills, knowledge and self-efficacy that contribute to employability take a considerable amount of time to acquire, and the whole process of developing employability is seen to be problematic (UKCES 2009). More recently this has been confirmed by a survey from the Hurst (2013) which found that more than half of major employers say the graduates they hire are not ‘work ready.’

Although graduates are entering employment with adequate technical skills, they often lack process skills such as communication, problem solving, teamwork and leadership that are necessary for successful job performance (Rao and Sylvester 2000; Adams 2013; UKCES 2009; UKCES 2014). Thus, tutors nowadays face a continuous challenge to teach students to think and solve problems like professionals in their fields by linking theory with practice. Furthermore, embedding employability into the curriculum requires much more than a bolt-on programme of skills, and it implies that the underpinning pedagogy of the curriculum provides both the opportunity to develop these attributes and an active scaffolding process to assist students to practice, reflect and improve.

I have successfully used problem-based learning (PBL) modules to achieve this aim. These modules have a mean attendance of 95% and a pass rate of 94% over the last seven years. This approach is underpinned by principles of independent and interdependent (team) learning which involve dialogue, critical thinking, and active problem-solving using relevant and authentic scenarios; principles that are consistent with, and promote employability attributes.

While PBL develops employability, it also enhances student outcomes in other ways: it can transform student expectations and behaviours bred by passive models of learning and teaching in compulsory education; it can encourage and reward creativity, initiative, critical thinking and ultimately encourage students to become self-regulated learners who can construct and apply their own knowledge, inspiring a love of a subject, the confidence of developing expertise and a desire for learning.

Here I describe my 16-year journey of exploring, experimenting, researching and developing PBL and I am confident that it achieves many of the goals outlined above. I will also discuss the difficulties I encountered – all was not plain sailing – and the lessons I learned. Finally, I present some examples, with explanations and suggestions of how to develop PBL scenarios of your own.

What is problem-based learning?

This section explains the motivation, philosophy, aims and process of PBL, and the pedagogical theory that underpins it. PBL originated in medical schools in the US in the 1950s and at McMaster University in Canada in the 1960s. Educators were concerned by the ineffectiveness of traditional information-laden lectures for developing professional competencies that required integration of knowledge, decision making, working with others and communicating with patients (White 1996).

PBL was used to shift teaching in medical schools from a collection of subjects representing individual disciplines to an integrative programme of study, engaging students in problem formulation and solving. PBL has also been adopted in many other areas such as Architecture, Law, Engineering, Psychology, English
Literature, Social work, Computer Science, Education and Business, demonstrating its applicability in a variety of domains – particularly those with an emphasis on professions and competencies that are now labelled ‘employability skills’.

A key theme in this paper is authenticity, and it is one that is particularly relevant for Computer Science. Later in this paper I provide details of how professional areas of Computer Networking and Network Security can easily be adapted to provide stimulating and effective learning environments. I also illustrate the struggles of using PBL for learning programming.

Developing a pedagogy for professional practice

Developing a pedagogy to improve professional competency required a paradigm shift from a transmission model of learning to one that more closely matched professional practice. PBL is both a curriculum and a process (Vernon and Blake 1993). The curriculum consists of carefully selected and designed problems that demand the learner acquire critical knowledge, problem-solving proficiency, self-directed learning strategies and team participation skills and experiences (Barrows and Tamblyn 1980). The processes replicate common approaches to solving problems encountered in real life.

Problem-based learning is characterised primarily by:

- an aim to develop students’ thinking and reasoning skills;
- stimulating learning through the presentation of an authentic problem (trigger) that students initially lack the knowledge to solve: this gap in knowledge drives the learning. Groups of students identify learning objectives from analysing what they know and need to know;
- self-regulated and interdependent learning in small groups, where students learn what is required individually, and teach others in the group. Knowledge is then applied by the group to manage or solve the problem. (Woods 1994)

The attributes of problem-based learning classrooms provide a framework for future learning (Wilson and Cole 1996). Advocates of PBL argue that it provides an effective environment for future professionals who need to access knowledge across a wide range of disciplines. PBL promotes behaviours that align closely with employer requirements.

Research to evaluate the effectiveness of PBL has shown that it promotes deeper approaches to learning (Newble and Clarke 1986) in an environment that is more stimulating and enjoyable (Albanese and Mitchell 1993). It enables students to enhance and retain self-regulated learning (SRL) skills (Barrows and Tamblyn 1980; Loyens et al. 2008) and helps students develop employability skills such as teamwork, problem-solving and critical thinking (Uden and Beaumont 2006). Furthermore, PBL is a learning system that Biggs and Tang (2011) identify as exemplifying constructive alignment, and consequently is regarded as good practice.

However, it cannot be claimed that there is general consensus regarding the advantages of PBL over traditional teaching: a brief review of published research by Clark (2006) identified conflicting evidence of research findings in areas of knowledge (test performance) and clinical skills, though there was stronger evidence in terms of student preference and enjoyment when engaged in self-directed learning.

Project-based learning and problem-based learning

There is often confusion between problem-based learning, case studies and project-based learning. They share some similarities: all use real-world scenarios, the approach is student-centred and the role of the tutor is that of facilitator or coach.

Although there are similarities, there is one critical difference: in problem-based learning students have not been taught the knowledge to solve the problem before they start. In case-based and project-based learning students are usually applying (and extending) knowledge that they have already learned.
Posing the problem first, before the learning of knowledge, motivates students to learn and while PBL predates Social Constructivist theories of learning, it aligns closely with some of the central tenets of constructivism as shown below.

**PBL is constructivist learning**

Savery and Duffy (1995) emphasise the importance of context in learning, stating that understanding is an individual construction based upon our experience with content, context and the learner's goals. It is impossible to separate the knowledge domain from the interaction in that domain. PBL's authentic, complex scenarios are the impetus for learning and feature the acquisition of both disciplinary knowledge and problem-solving skills.

Secondly, a critical feature of the pedagogy of PBL is that cognitive conflict or puzzlement stimulates learning. The goal of the learner is central in considering what is learned. It is not only the stimulus for learning, but it is a primary factor in determining what the learner attends to, what prior experience the learner brings to bear in constructing an understanding. Loyens et al. (2008) highlighted that the self-generation of learning objectives is crucial and beneficial for students' learning process (Verkoeijen et al. 2006).

Finally, understanding is influenced through the social negotiation of meaning. Knowledge does not represent some ultimate truth, but is simply the most viable interpretation of our experiential world. Social negotiation of meaning and understanding is based on viability (Savery and Duffy 1995). The best PBL scenarios are open-ended, similar to those students would face in the workplace and provide for multiple solutions, and students work in teams to argue and justify their conclusion.

Self-regulated learning has been mentioned several times so far, and it is worth elaborating this concept further, since it is an essential component of PBL where students identify and work to achieve their self-defined learning goals.

**Self-regulated learning and PBL**

SRL includes processes such as goal setting, planning, self-monitoring and instruction and self-assessment, together with motivational beliefs (Zimmerman and Schunk 2008).

Zimmerman and Schunk claim that students who are good self-regulators

- set better learning goals, implement more effective learning strategies, monitor and assess their goal progress better, establish a more productive environment for learning, seek assistance more often when it is needed and expend effort and persist better. *(Zimmerman and Schunk 2008, p. 1)*

It is therefore clear from the start that PBL aims to be consistent with SRL.

Interestingly, Beaumont et al. (2008; 2011) reported that many university tutors lament the lack of SRL skills exhibited by students, and pointed to the lack of guidance or teaching of the required skills. As the next section shows, PBL provides a process for problem-solving and effectively models the key elements of SRL.

**How does it work? The problem-based learning process**

Different authors define a variable number of steps in the PBL process. The steps provide a problem-solving structure, essentially an scaffold for dealing with the unknown. For example, Barrows and Tamblyn (1980) summarise the PBL learning process as follows:

1. the problem is encountered first in the learning sequence, before any preparation or study has occurred;
2. the problem is presented to the student in the same way as in real life;
3. the student works with the problem that allows him/her to reason and apply knowledge to be challenged and evaluated, appropriate to his/her level of learning;
4. Learning issues are identified while working with the problem and these are used as a guide to individual study;

5. Skills and knowledge learned by this study are applied back to the problem to evaluate the effectiveness of learning and to reinforce learning;

6. The learning that has occurred by working with the problem and in individualised study is summarised and integrated into the student's existing knowledge and skills (Barrows and Tamblyn 1980, pp. 191-2).

Irrespective of the number of discrete steps, the process can be conceptualised as four stages in a cycle, which may be repeated. The initial stage comprises the understanding and exploration of the problem to define what is known, unknown and needs to be learned. This aligns with the SRL ‘forethought’ phase, employing skills of goal setting and planning. The second stage requires individual research, learning and SRL, the ‘performance’ phase, employing learning and monitoring skills. The third stage, problem-solving, involves team members teaching each other the relevant information and applying the learning to solve or manage the problem. Finally, the fourth, reflecting stage, aligns with the SRL ‘self-reflection’ phase, with students practising skills of self-assessment and causal attribution.

**Figure 1: The problem-based learning cycle (Beaumont and Frank 2003)**

Learning is the main aim in PBL, not the completion of the task. The main focus of PBL is to confront students with a problem to solve as a stimulus for learning (Boud and Feletti 1997). The problem does not test skills, but assists in the development of the skills themselves.

It is important to note that there is not a single ‘pure’ version of PBL; PBL is a flexible approach that can be adapted to different purposes and environments. One useful way of distinguishing models of PBL is provided by Maggi Savin-Baden (2000) where she identifies five models, ranging from ‘PBL for epistemological competence’ (learning disciplinary content) through ‘PBL for professional action’ which focuses on ‘know-how’ and application in a professional context, and further models that focus on interdisciplinary and transdisciplinary learning, to more abstract forms which explore underlying structures and belief systems.

**Assessment**

A consequence of adopting PBL is that methods of assessment need to be reconsidered. As soon as students have elements of choice and control over their learning, assessment becomes more complex. Furthermore, there can be conflict between assessing PBL and prescribed learning outcomes. If traditional methods such as examinations are used, students immediately start asking if what they are learning ‘is on the exam’. This
does not mean exams are impossible, but they should be designed to align with PBL wherever possible. For example, a seen exam, or a case study-based exam with the case provided in advance and unseen questions can be effective.

Authentic real-world scenarios can provide good opportunities for assessment that measures elements of professional competency – what students do, rather than simply writing about it. Presentations, technology builds (software or hardware) and professional reports can be suitable activities and artefacts.

A perennial problem with any form of teamwork is assessment, particular determining an individual's contribution and grade. A team artefact such as a report cannot easily be disaggregated and words do not always correspond to contributions, such as ideas, discussion and work done. There are numerous approaches published to deal with assessment of group work, and this paper will discuss the method I have adopted to overcome difficulties I found.

Finally, there is the question of assessment of skills. If we value teamwork and other skills, it makes sense to assess them. However, that also implies that we provide effective coaching methods to help students develop them. The McMaster skills programme that Woods (1994) describes is very extensive. Adopters of PBL need to determine in advance how they will deal with these issues.

In this section I have explained why PBL has been developed: primarily to improve learning for professional practice, and I have outlined how it is organised at the macro level. The pedagogical theory that underpins it is consistent with good practice and there is plenty of evidence for its efficacy. PBL is a complex approach that develops skills and attributes that are highly relevant to the employability agenda and improves student motivation. However, it is clear that it is a very different approach to that experienced by most students (and staff), so it is important to plan the introduction of PBL very carefully. The next section will explain the approach that I took, and explores both the successes and difficulties I experienced along the way.

**The story so far**

In this section I will share the journey that I took when developing my approach to PBL. The previous section has carefully been constructed to show how PBL aligns with well-founded pedagogical principles and employability initiatives. It sounds too good to be true, and indeed there are pitfalls – the devil is always in the detail.

For me it started in the 1990s, when I was teaching a 12-week 15-credit Level 5 introductory Computer Networking module in a conventional way using theory lectures, labs and workshops. Each week I would introduce students to the theory during the lecture, followed by a lab session which had activities to illustrate the principles and consolidate the learning – or, at least, that was the idea. The labs were supposed to represent ‘active learning’. Sadly, they might have been active, but it became clear that learning was limited. Checks the following week showed very poor knowledge retention, and it seemed that labs were followed without any intellectual engagement – or possibly understanding. It simply didn't work.

I was first introduced to PBL at an assessment conference at Northumbria, and David Boud's (1991) book, *The Challenge of PBL*, provided sufficient detail to get started. For me the attraction was that students had to find answers for themselves, and it was relevant with real-world problems. I could see how it could be motivational, and Computing fitted the bill with plenty of real-world scenarios. My aims were to develop professional subject competency, employability and motivation.

However, it meant turning the module upside down, and finding one or more authentic scenarios that enabled learning outcomes to be met and which were big enough for teamwork. Scenarios with more than one acceptable solution would be best, and those that were cross-disciplinary were recommended in the literature. This meant planning out the entire semester in advance, and significantly, identifying the likely learning objectives students would generate in the scenario, together with suitable and available resources
that they could use. The latter was necessary, not to give students the resource list, but to ensure that it was possible for students to do what I was asking.

Don Woods (1994) suggested that each PBL scenario should be organised as a minimum of two team sessions separated by individual research. In the first team session students explore the scenario, identifying learning objectives and allocating them to team members to research. This is followed by individual learning. Finally, there is a team teach session in which students share their learning, and apply their knowledge to manage or solve the problem. Following the conclusion of the PBL scenario, students reflect on the team process and quality of solution.

Furthermore, Woods recommended that students work in small teams with a facilitator per team, with each team having a suitable base room. This latter requirement was not possible in a lab environment with of a 20 students to manage in weekly three-hour timetabled sessions.

Another challenge was assessment. The assessment model for this module included an exam and portfolio of network exercises/small problems. At this stage, I considered that basic technical knowledge about such things as Ethernet, Transmission Control Protocol/Internet Protocol (TCP/IP) switching, routing, IP addressing and the Open Systems Interconnection (OSI) and TCP/IP models was best assessed by multiple choice exams. The exam also provided reliable individual assessment and mirrored professional exams from Cisco, Microsoft and Novell. Application, evaluation and synthesis of network solutions could be assessed by a professional report and presentation.

My first attempt consisted of a scenario wherein students were required to design and construct a network for a small company. It was based on a commercial training company for which I had worked, and hence I could make it realistic. The brief was for students to act as consultants, designing and presenting a network solution to meet the company needs, in competition with other teams. The brief was deliberately vague, so students had to interview key staff to elicit requirements. I roped in colleagues to play the roles of Sales Director, MD and Training Centre Manager (each having different perceptions of the purpose of the system). The solution would be presented to the ‘company board’, together with a report. Students would build a demonstration network with three personal computers (PCs) plus switch and install application software. This scenario would last most of the semester, divided into stages – PBL1: determining the specification; PBL2: designing a solution; and PBL3: building a demo network.

The learning outcomes of the module had to be expanded to include soft skills (including teamwork, presentation and interviewing). Since teamwork is considered important, it had to be assessed and I used a mixture of peer assessment, attendance and in-class performance as measures. Resources had to be provided to enable students to research good methods of conducting interviews to elicit information.

The scenario required students to understand networking topologies (at this time, token ring and bus networks were not quite dead, so a critical evaluation of Ethernet/token ring was required with physical layer cabling, network components (hub/switch/bridge/router etc.)). Peer-to-peer vs client-server networking, addressing, and routing were also required. There was scope for extension in terms of security (firewall etc.) and students had to learn how to configure either Novell Netware or Windows NT Server networks. Thus, there was a rich variety of research required, which could span most of the semester, together with the network build. It soon became clear, however, that traditional parts of the course, focusing on data communications, for example TCP/OSI models, subnetting¹ and TCP handshake², were not obvious learning

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¹ Subnetting is a process of dividing large network into the smaller networks based on layer 3 IP address.
² The TCP three-way handshake in Transmission Control Protocol (also called the TCP-handshake; three message handshake and/or SYN-SYN-ACK) is the method used by TCP set up a TCP/IP connection over an Internet Protocol based network.
objectives. I therefore sacrificed some 'sacred cows' such as the TCP handshake and subnetting in this module.

I had to think carefully about the organisation of the module, and how to introduce students to a radically new approach. I introduced PBL through a lecture (the irony wasn't lost, but it is a method with which students were familiar). It was short and gave opportunities for questions. Students selected their own teams during the process and discussed concerns and fears they had about PBL. I selected teams of four to five students (in a class of 20 students) since these ‘felt’ appropriate to the scale of the problem and my experience of successful group work in other Computing classes. This was smaller than the medical school model, which typically had team sizes of 10-12 students. In my view, the scenario could not sustain large team sizes and I was concerned about freeloaders. I did not have additional tutorial help, and had been timetabled one three-hour session per week. I adopted a ‘roving facilitator approach’ spending approximately 20 minutes with each team in rotation. I was concerned about the possibility of inappropriate and insufficient learning, and giving control to students was definitely scary.

They say the proof of the pudding is in the eating. Attendance levels were excellent (95%) and much better than previous methods, as the teams themselves helped self-policing attendance. Most students engaged well with the process and tasks, however, this was their first experience, and facilitation was more directive than I would have liked: I had to make the judgements on how far to push students. When I sensed there was a high level of frustration (you can only reflect questions and ask ‘why’ so many times) I had to make a judgement of what information to provide. It had to be minimal, as students are immensely skilled at playing the game of ‘chicken’: some believe that if they hold out long enough, the answer will be provided. Furthermore, my roving facilitator approach made it more difficult for me as I was unable to hear the whole of the team discussion. It was quite exhausting and complaints about freeloaders still arose.

The variety of activities - interviews, presentations and network build – motivated the students and were seen as appropriate assessment activities, which were fully embedded in the module. However, the exam was problematic. To ensure students were aware of the type of content and questions, a sample exam was provided through the virtual learning environment (VLE). The results were not a problem, but the exam stood out on its own, and was not integrated within the PBL scenarios.

Another (quite predictable) issue concerned freelading, something which upset hard-working students who complained that their mark was brought down by poor contributions from freelading students, who then benefitted unfairly. In response I tried various forms of peer assessment, to allocate team marks according to contribution. However, this too, was unsatisfactory. I had instances of students victimising a team member or alternatively favouring their friends.

After various attempts to solve these issues over several years, I have opted for a system that works for me. I no longer use examinations. Assessment is divided between an individual portfolio of research handouts and various team artefacts/activities. During the individual research phase of PBL, I now require students to produce a two to three-page handout that consists of the research question, a brief summary of findings and how the knowledge can be applied in the scenario, and finally details of the research. Students use the handouts to teach each other in the ‘sharing’ session. A final portfolio entry consists of an individual reflective piece, in which students explain their contributions to the PBL scenarios, including any evidence of leadership and a statement of ‘working with others’, marked against a set criteria (worth 10% of the module). Example criteria are shown in Appendix 2.

This approach has worked well. It evidences individual work, and it helps students focus on expressing research questions and summarising the findings in their own words. It also ensures that they consider the relevance of the findings by applying it to the scenario. A portfolio of four to five handouts which show criticality and application of the knowledge to the scenario can achieve a top grade. After trying several alternatives, I weight this component at 70%. This ensures that the grade a student obtains for the module is largely determined by their individual work.
I always commence the module with a formative PBL scenario, to introduce students to the method, so they get used to working with one another. Subsequent scenarios have progressively higher team weightings. The integration of assessment, teamwork pressure and progressive interdependency between successive scenarios has meant that I have not experienced deliberate non-submissions. An example of grading criteria and an example research handout is provided in the appendices.

*Extending beyond a single module: Level 6 module in Network Security*

There are advocates of PBL who suggest that the entire curriculum should be problem-based. However, Boud and Feletti (1997) point out that you can have too much of a good thing, and a variety of pedagogies is preferable. Indeed, PBL is demanding and puts learners under significant stress as they have to decide what is relevant, and when they have learned ‘enough’ for the scenario. I decided that one module each year would not unduly stress my students, so I introduced a Level 6 module in Network Security. As an elective module, I ensured students were fully aware before they made their module choices that this would involve teamwork and PBL (some students deliberately avoid teamwork despite its employability benefits). Some students who studied this module were therefore already familiar with the PBL process, and it was immediately evident that they progressed much more quickly. The contrast was very marked, and emphasised how much time was spent at the introduction of PBL in getting used to the process.

This module has 12 three-hour lab sessions in a semester, each accommodating up to 20 students, divided into four self-selected teams. Around a half of the students taking the module now join from Foundation degree partner colleges for the top-up year, and arrive with no knowledge of PBL. Thus, the first week is devoted to team formation and explanation of PBL. Learning is driven by four PBL scenarios. The first PBL (formative) in week one is directive, specifically to model the process. In week two students share individual reports and synthesise a team presentation which is delivered immediately in class.

### PBL 1 scenario: Information security management

NVQ Services Ltd is a small company with 60 employees. The company performs NVQ training, assessment and consulting throughout the North West of England. It has just appointed a new network administrator (Clare). The company runs a small local area network (LAN), with access to the Internet. Servers on the LAN hold client data, financial data and various other pieces of internal information. In her previous employment, Clare had attended a course on an international standard ISO27001: 2013 (*Information Security Management*). Her previous employer was in the process of going for certification under the standard. Clare is concerned about the security systems in NVQ Services Ltd and suggests to the Managing Director (MD), Susan Jones, that the company might consider ISO27001 and that they should set up a security forum to identify assets, risks and associated protection needed. However, the MD is less than enthusiastic, saying that “Security is a technical issue, and that is why she employed her. There is no need to waste more management time on yet more meetings!”

**Your task**

You need to *individually* write a short (1,000 word) report to assess to what extent the MD is correct.

At this stage, facilitation focuses on helping students analyse the scenario and pick out learning objectives (E.g. what is InfoSec? What is ISO27001? What are assets and risks? Is security just a technical issue? Suitable resources are available from the VLE at this point.). Despite the purely formative nature of this task, engagement has always been very high.

The second scenario is introduced in the second session following completion of PBL1. This is summative, but worth just 3% of the module. It aims to prompt students to explore E-commerce security issues and solution technologies, including encryption and Transport Layer Security (TLS). The use of disagreements between individuals in the scenario has proved a useful device for prompting critical discussion and giving cues for investigation (in this case the types of encryption, Public Key Infrastructure and how they work).
PBL 2 Scenario: E-commerce security

As part of their product offering, NVQ Services Ltd have now started publishing 'quick start' software guides to accompany their training courses and they want to allow these to be purchased via the Internet through an e-commerce website.

The MD is concerned about the security aspects of this, and she is particularly worried about secure payments. She has decided that she will only accept credit card payments as she believes that this ensures that the purchaser is genuine.

However, she is aware that there is a legal requirement about keeping data confidential both when stored on NVQ Services' computer and also in transit across the Internet. She has heard that the way to do this is with 'Secure Sockets Layer (SSL) and encryption' but hasn't a clue what SSL is or how encryption works.

She has also heard that this uses 'symmetric secret-key encryption' and that it is not safe because criminals could use a 'sniffer' to eavesdrop on the communication, steal the data and decrypt it since the encryption is a weak 40-bit key.

Furthermore, she is also concerned that customers may be directed to a spoof website instead of NVQ Services' site and wants to know how they can be sure they are buying from the real (authentic) site when they send their credit card details.

Claire, the technician, thinks the MD has got the wrong end of the stick again, and says that SSL uses Public Key encryption, rather than symmetric key encryption, which she claims is much more secure.

The MD is unconvinced, claiming that "a public key must be less secure than a symmetric secret key since everyone can see it!" Claire also suggests that the company purchases a Digital Certificate and also needs to become a Certificate Authority, to solve the authentication issue.

Your task

There is quite a bit of confusion here, and your job is to provide a succinct (team) report (and presentation) to address the security concerns around e-commerce and determine if the MD or Claire (or neither) are correct in their statements.

At this stage, facilitation aims at prompting students to develop a set of well-formed (specific) research objectives for their individual work. Most of my students naturally write vague objectives such as 'Research encryption' which yield equally vague results. Prompting them to be specific and specify the context helps focus the research and apply it: for example: 'Explain the types of encryption used to provide security in e-commerce transactions'. An example student handout is shown in Appendix 1. The template requires research objectives, a very brief summary of findings, a recommendation for applying the knowledge to the scenario and further details of the findings. Students are asked to limit their handout to three pages to promote the skill of summarising in their own words. At least two students in each team research each learning objective, to improve validity.

This approach ensures students are working on this module every week, and it is easy to monitor engagement. Each PBL scenario has a new team project manager, whose job includes chasing students if necessary and co-ordinating team work submissions.

This scenario is run over three sessions – week one: the introduction; week two: sharing and planning the report and presentation; and week three: delivering the presentation and submitting the team report.

The remaining scenarios comprise the design of a secure network (PBL3) and finally constructing a demonstration network (PBL4) from six PCs and three network switches. It also requires configuration of client PCs, a firewall, Domain Name System (DNS) servers, a domain controller, web servers etc. Five weeks are given over to the build and subsequent demonstration (assessment) of the build.

Grading criteria are provided in Appendix 2. Since PBL2 has a small weighting, only Fail/Pass and Distinction grades are distinguished. Individual criteria for the portfolio and teamwork are also provided. Instead of peer assessment, team working ('working with others') is graded by assessing a portfolio entry which is a reflective claim providing evidence against the criteria.
Given the scale and progressive nature of these scenarios, the roving facilitator model is just about workable for four teams in this environment for the first three scenarios. The build throws up so many technical problems that I arrange for a technician to provide additional support at that time. Students are also offered the opportunity for submission of a draft portfolio of research handouts for formative feedback prior to final submission at the end of term.

**PBL and programming – a new challenge**

Buoyed by the success of the previous modules, I considered the ideal to have PBL in all three undergraduate years and introduced at Level 4 when they were most receptive to change. It appeared a golden opportunity to address the challenge of teaching the notoriously problematic subject of programming. (Beaumont and Fox 2003)

Jenkins (2002) suggests many reasons why programming is difficult to learn. It involves multiple skills including problem solving and algorithm development; it requires students to use quite complex Integrated Development Environments (IDEs) and it involves a hierarchy of skills and knowledge from syntax to the analysis of problem statements, synthesis of solutions and evaluation against the specification. Furthermore, for most students, programming is very different from their other learning experiences, and thus difficult to relate to existing knowledge. Dijkstra (1989) refers to this as “radical novelty”.

At the time I discovered that Judy Kay and her colleagues at the University of Sydney had been using PBL in first-year programming classes since 1996. Her initial trial was evaluated and in a three-year longitudinal study she concluded that PBL students learned as much knowledge (judged from exam performance) as traditional students. They also learned additional skills, which were judged important: planning, research, communication, self and peer assessment, and integration of code written by other team members.

This sounded promising, so I explored how the PBL process could address some of the difficulties associated with learning programming.

**Problem solving**

In many traditional programming courses, problem solving is taught by example. Students are expected to generalise from specific examples, apply knowledge in differing contexts and gradually acquire problem-solving skills. In PBL an explicit method is taught. Small problem-solving activities can help students separate out and practice problem-solving techniques from the other areas of learning programming. An example is the pairs speak-aloud exercise (Woods 1994).

**Hierarchy of skills/knowledge**

The PBL cases are ill defined and typically have ambiguities and leave a number of issues for students to investigate and resolve. This provides freedom and considerable control for students, which stimulates creativity. It is essentially a ‘top-down’ approach where teams decide what they want to happen before working out how to make it happen. Graphic user interfaces (GUIs) lend themselves to a storyboard approach and active coaching can make sure that they identify issues of validation, human-computer interaction (HCI) design principles, test plans etc.

A weakness attributed to PBL is that students do not learn basic facts and declarative knowledge as well as those employing traditional methods. Since programming requires extreme accuracy and a considerable body of detailed knowledge of syntax and semantics, this poses a problem, and was regarded as a high-risk area.

Therefore the PBL cases were designed to progressively require students to develop knowledge of particular fundamental constructs (e.g., variables, conditions, loops, procedures, arrays and files). The initial cases involved fixing faults in prototype programs and then enhancing their functionality and interfaces. Resource
materials were sample code and self-paced teaching materials. The PBL cases pointed students to suitable chapters of the self-paced materials and other appropriate resources.

Pace of learning

In PBL the students control the pace of learning. They identify learning objectives for themselves.

Don Woods points out that with PBL the content of the curriculum needs to be reduced by 20% to allow time for the PBL process. In first year students, who have to cope with enormous change in their lives, we decided to reduce subject content by 30%-40%. We decided it was much better to be able to develop basic competency and confidence than awareness and 'learned helplessness'.

Educational novelty

PBL can do nothing about the radical novelty of programming, however it can help students manage this through teamwork. Learning is a social process, and using teams to require students to discuss all difficulties, document and identify a way forward, and explaining to each other solutions they discover, is an effective management technique. It also enables facilitators to identify common issues and develop resource or activities to assist.

Complexity

The multiplicity of skills, required for conceptual thought, covering all levels of Bloom's taxonomy, certainly introduces a high level of complexity. PBL appears to increase complexity by introducing teamwork, research, planning, co-ordination, dealing with conflict, additional communication and dealing with ambiguity and ill-defined problems on top of the technical issues.

The commonly accepted way of dealing with complexity in Software Engineering is to divide and conquer: Modules/objects/classes with well-defined interfaces, loose coupling and high cohesion.

The PBL approach imposes a systematic discipline of analysing problems, identifying learning objectives, solving the smaller learning objectives, and integrating the solutions. It therefore teaches a method of managing complexity which has many parallels with Software Engineering.

Other considerations for first year students

The widening participation agenda has resulted in a diverse student population at Edge Hill and there are additional issues for all subjects. New students are often ill prepared for university study and changes have been identified as necessary in order to improve retention, ensure students are effectively inducted to university study and are adequately prepared for the demands of the second and third year programmes.

PBL is seen as helpful in a number of ways since it promotes the formation of friendship groups through teamwork. This is particularly important during the first few weeks of university life. PBL has been found to be motivational – improving performance and reducing dropout. When Manchester University's School of Engineering introduced PBL it reportedly resulted in a reduction in dropout rate from 15% to 5% in year one, semester one.

PBL also naturally integrates the teaching, development and assessment of key skills which are no longer perceived as ‘another add-on' to the curriculum.

Experiences

The theory can sound convincing, but does it work in practice?

3 Personal communication
The first problem – formative

In the first week, students were introduced to PBL and team-building exercises. The PBL case consisted of three prototype interfaces for bank account transactions, which partially worked. Students were required to find out how they worked, fix them, then evaluate the best interface and produce an enhanced interface. Initially each pair in the team worked on one prototype and finally the team produced their final application, delivering a presentation and report. It included assessment of key skills.

The presentations were delivered at 9am on a Monday morning in week four of the semester. All students were present on time, delivered high quality presentations and gave constructive feedback on others. The only weakness was in the identification and application of HCI criteria. Yet this was a formative assignment. In previous years students would only put significant work into summative assessment. All tutors were surprised at the commitment, motivation and quality of the work. Perhaps we have been underestimating students for decades!

The second problem – summative

The second problem followed the same pattern, and the same student teams, but required additional technical knowledge. A prototype animated game was provided (with faults). This required the use of arrays and some tricky logic for working out the animation. Students had additionally to apply more formal HCI heuristics (from Neilson and Molich 1990), coding standards and a test plan. Again student teams presented their enhanced prototypes, but this time had to test each other's. Surprisingly for the tutors, the standard of presentation, motivation and commitment were reduced.

Subsequent PBL cases comprised a research report about object-oriented technology, implementing Belbin's team roles questionnaire (requiring files, 2D arrays and procedures). The final PBL case required students to individually code part of a game (each student took one level) and then integrate their applications.

Successes

The initial motivation levels were extraordinary, and the work was of a very high standard.

Facilitators

Initially each class started with one academic and two final year students as ‘Learning Team Coaches’ (LTCs). LTCs had experience of PBL in the Level 5 Networking module and had attended a one-day training workshop prior to the start of the semester. Meetings were arranged weekly/fortnightly to discuss issues and provide support.

The LTCs proved reliable, committed and effective at facilitating student teams. They achieved the delicate balance between being active but not directive. They were perceived very differently from the tutor, even in the facilitator role. A particular (unforeseen) benefit of using students as LTCs is that they are viewed as peers, and often discover important information about student attitudes, behaviours, progress and intentions that the first years are unwilling to reveal to tutors. In subsequent years we validated a module to enable LTCs to gain academic credit for the work (as well as pay at the standard casual rate). It proved particularly popular for students planning to progress to a PGCE.

Issues

Team commitment

Group working is often problematic in undergraduate courses, particularly commitment, contributions and attendance. In this PBL approach we introduced specific features, exercises and peer assessment to focus on these issues. We also introduced penalties for non-attendance at a meeting without prior notification and non-completion of work. Students could win back marks by putting in extra work.
For the majority of students this was effective. However, a small (but significant) number of the younger students did not exhibit the desired team working behaviours. Mature students adapted much more quickly. It is easy to blame the individuals, but on reflection students' prior experience of education is very much focused on the individual up to the age of 18. Perhaps we were expecting too much. The teams allowed students to hide ignorance – the research handout approach used in the previous modules wasn't applicable for learning programming – there was little existing knowledge that could be activated and too many students did not achieve competence at the basics of coding.

Consequently in future years we restricted the PBL approach to the final quarter of the year and refocused on individual work which introduced concepts via Alice, an intuitive 3D programming environment (www.Alice.org), and introduced Java and NetBeans in the second half of semester one. The PBL part of the year used Lego Mindstorm programmable robots, providing plenty of opportunity for initiative and open-ended development.

While the PBL approach was diluted over the years, we wished to build on the success of LTCs, and this approach has successfully continued for more than 10 years. Students need considerable support to learn programming (e.g. deciphering errors) and LTCs have been very effective, while developing their own interpersonal and teaching skills.

So what?

I have selected these case studies to show contrasting examples. The Networking and Security case studies successfully engaged students in authentic activities that integrated theory and practice. They were effective at motivating students (evidenced by attendance, pass rate and student feedback). Students report their experiences as transformational; recent graduates also demonstrate how this type of learning can transfer into the work situation:

I am very excited about my experience of studying the modules delivered. PBL has changed my view of learning and provided me with a new approach to the study; I have been applying its methods to daily situations in my workplace.

Your [PBL] security module has proven EXTREMELY helpful in my new job

PBL yielded substantial benefits as experienced by both students and tutor. Irons and Thomas (2014) found similar positive results when using PBL in Digital Forensics.

On the other hand my programming initiative was not successful when a wholly PBL approach was attempted with first year students. We believe that this is caused by a mixture of the novelty of both PBL and programming, together with the need for expert help (rather than help from peers) and the extreme accuracy required which had an adverse effect on novices. However, a modified approach which introduced PBL scenarios that extended programming knowledge (rather than initiated knowledge) has proved successful.

Further evidence to support this explanation is a successful blended approach used in a Level 6 module in which students learned database programming (Beaumont et al. 2008). These were experienced university students with some programming knowledge which they were able to activate and extend.

Are you tempted to try PBL?

There are clearly many differences between PBL and the transmission model of teaching, however, if we set aside labels, it is also clear that there are principles and aspects of PBL practice that are often incorporated in many courses and I would argue that there is a continuum of pedagogical approaches from what might be regarded as ‘pure’ transmission, in the archetypal lecture, through to ‘pure’ research. Problem-based learning sits somewhere near the research end.
Since learning is complex, institutional contexts differ widely and PBL changes many aspects of the learning system. Lorna Uden and I (Uden and Beaumont 2006) posed the following question to a wide range of PBL researchers and practitioners:

What’s the most important advice you could give someone just starting to use PBL?

We received replies from locations as diverse as Australia, Finland, Mexico, Alaska and the UK, which provided a global perspective.

There were three themes that were prevalent: the importance of preparation; the likelihood of criticism and difficulties, and the need to adapt to your local situation.

**Preparation and planning for change**

Perhaps unsurprisingly, preparation and planning were cited as essential.

A key learning point for me over the years has been that PBL forces us to challenge our preconceptions of the knowledge that is professionally necessary and relevant. Content also needs to be reduced to make space for team learning.

Pedro Gordan (2004) helpfully identifies four areas for preparation and planning: goals; people; information; and resources, which are also supported by other respondents.

The goals for PBL are usually broader than cognitive objectives, encompassing process skills.

“Be clear about the purpose for introducing PBL and the learning outcomes” recommends Jim Wood. Knowing those outcomes will determine every other piece that goes into the structure of the PBL experience. *(Linda Dislehorst)*

The people dimension is reported as being one of the most problematic. “People have been used to traditional ways of teaching for a few thousand years,” points out Markku Suni. “Thus it is rather natural to expect teaching going this way.” So preparing the stakeholders for the change – both staff and students is critical to success.

The biggest difficulties were reported as being the adaptation of staff, rather more than students:

It is difficult for teachers to change, especially for the "experienced" teachers who believe what they have been doing is right. *(David Rawcliffe)*

One of the chief concerns students have reported to me is that of facilitator style, ranging from the person sitting in the corner, who occasionally says 'why' to the tutor, to the person who dominates the team and will not let them leave until they have identified every learning objective in his/her facilitator guide.

Finally, resources are a particularly practical consideration, so careful planning and preparation of the physical resources (rooms), learning resources (library) and financial resources, are needed.

**Expect difficulties and criticism**

The second theme concerned criticism and difficulties, most of which are related to the people aspect identified above. PBL is challenging to students and staff alike. Change can bring feelings of insecurity and this can manifest itself as hostility and criticism from both faculty and students.

PBL is utterly unlike most other education [students] will ever have encountered. It entails real engagement and it is pretty well impossible to drift or mug up at the very end of the semester. Students like everything in bite-sized chunks these days and PBL gives them an oxen rather than a beef burger. *(John Bradbeer)*

Furthermore, while ‘learning starts from where they are’, this only works if students are prepared to be honest. We have discovered that many students still avoid acknowledging ignorance when they perceive their
peers know more. This behaviour has been ingrained for years, we expected students to be open, but in many cases this has not been the case.

**Adaptation and variety**

It can be tempting to implement an existing model of PBL by taking it 'off the shelf' from another institution. After all, there would appear to be a good rationale for it: if you adopt a tried and tested approach you would expect to encounter fewer difficulties and save a considerable amount of development time.

However, one of the strongest recommendations from our respondents was to avoid wholesale copying of a model from another institution. There are a number of reasons for this. Firstly, from a change management perspective, ownership of the change by faculty is critical for a successful outcome and this is difficult to achieve if a curriculum and model are transplanted from another institution.

There are many varieties of PBL but they do not come à la carte. *(Derek Raine)*

The second reason for modifying and adapting a PBL model is to make it appropriate for the particular context that you are in. The subject, the institutional culture and resources, the experience and ability of students are all factors that are important in devising learning experiences that are effective. After all, PBL is consistent with constructivism, which places a strong emphasis on prior experience of the learner.

This does not mean that you should always reinvent the wheel, but adaptation is important so that the teaching and learning model is appropriate and relevant for your students and your faculty.

PBL is not a tool, it is a philosophy. It should not conflict with the learning environment. Thus, workloads and timetables must be consistent; the physical environment must be consistent. *(Derek Raine)*

Ranald Macdonald relates this back to the fundamental motivation for examining teaching and learning:

> My advice would be not to get too hung up on models but to look at learning and how best to improve it. This often means including a variety of experiences (including assessment) rather than some of the rather dry, formulaic approaches to PBL that have appeared, with which students (and staff) readily get bored. *(Macdonald 2002)*

This is a critical point: problem-based learning arose out of the aim to improve learning for professional practice and dissatisfaction with traditional methods. Quite often, when labels are attached to a new method, the original aims can almost be forgotten, and a cult can grow up around the label. In recent times there has been much hype about the 'flipped classroom' approach as though it is revolutionary. It has been a feature of PBL for decades.

**Conclusion**

This paper has explained my approach to PBL. It is a pedagogy which, if used well, can motivate students, and can develop a student’s subject knowledge, self-efficacy and skills that employers consider essential. The subject discipline of Computing is a particularly rich area for devising real-world scenarios that are relevant to our students.

There is significant work ‘up front’ to convert traditional modules to PBL, but it can be done in small chunks, introducing a short PBL scenario to extend and challenge knowledge. I would encourage you to reflect on how you can integrate PBL into your teaching – it can be rewarding for both students and tutors.

The examples provided align with Savin-Baden’s (2000) model of PBL for epistemological competency and Professional action. Students have reported it as particularly effective in developing employability in the 21st century, for example, Baden (2000) quotes one student’s feedback:
an outstanding aspect of my course [which] familiarised me with business environments and gave me experience of dealing with colleagues in a professional setting. (Baden 2000)

References


HEFCE (2011) Opportunity, choice and excellence in higher education. Bristol: HEFCE.


Appendix 1: Example research handout

Produced by student (Nicco Deblasi used with permission) for PBL2

Research questions:
What is a key?
What is Symmetric Key Encryption?
What is Asymmetric Key Encryption?
Does SSL use Symmetric or Asymmetric Key Encryption?

Summary of findings:
A key is ‘the input data into the algorithm that transforms plaintext into ciphertext or ciphertext into plaintext’ (Maiwald 2003, p. 249). The size of a key is measured in bits, the larger a key, the more encryption code possibilities.

In symmetric encryption algorithms, encryption and decryption happen using a shared unique key (Arregoces and Portolani 2003).

Asymmetric encryption uses two keys; a public and private key. The private key is known only by the owner and not shared with anyone else, whereas, the public key is given to anyone who wants to communicate with the owner of the private key. The keys are set up so that they are the opposite of each other, anything encrypted by the public key can only be decrypted with the private key (Cole 2002).

TLS/SSL uses both symmetric and asymmetric encryption.

Recommendation:
NVQ Services is recommended to use TLS/SSL to provide confidentiality and integrity during transmission of data and will therefore utilise both methods of encryption.

Details and explanation of findings:

What is a key?
A key is ‘the input data into the algorithm that transforms plaintext into ciphertext or ciphertext into plaintext’ (Maiwald 2003, p. 249). Without a key, an encryption algorithm would produce no useful result.

What is Symmetric Key Encryption?
In symmetric encryption algorithms, encryption and decryption happen using a shared unique key. As both the sender and receiver share the same key, it is vital that it is maintained in secrecy, as if anyone else happened to gain access to the key then they would be able to decrypt any messages they intercepted (Arregoces and Portolani 2003).
Jackson (2010) states that the main benefit of symmetric key encryption is that it is very fast and does not require as much computing power as other key encryptions. However, Jackson (2010) goes on to state that a big downside to this method of encryption is managing and distributing the keys. This is because symmetric encryption by itself has no way for sharing keys across a public network in a secure manner, and must depend on other protocols or preinstalled keys.

Symmetric key sizes are typically 128 or 256 bits. This means that a 128-bit key has $2^{128}$ encryption code possibilities, with a 256-bit key having $2^{256}$. As a result, a brute force attack would take a long time to break a symmetric key (Digicert 2015).

**What is Asymmetric Key Encryption?**

Asymmetric encryption overcomes the shortfalls of symmetric encryption by using two keys; a public and private key. The private key is known only by the owner and not shared with anyone else, whereas, the public key is given to anyone who wants to communicate with the owner of the private key. The keys are set up so that they are the opposite of each other, anything encrypted by the public key can only be decrypted with the private key (Cole 2002).

Richardson and Thies (2012) state that the advantage of asymmetric encryption is that management and distribution of public keys does not need to be done in a secret and secure manner. This is because both the public and private keys are required to decrypt messages. However, Richardson and Thies (2012) state that a downfall is that asymmetric encryption requires a large amount of computing power and as a result is slower than other key encryptions.

Asymmetric keys are typically 1024 or 2048 bits. This means that a 1024-bit key has $2^{1024}$ encryption code possibilities, with a 2048-bit key having $2^{2048}$. To put it into perspective, it would take an average computer 14 billion years to crack a 2048-bit key (Digicert 2015).

**Symmetric vs Asymmetric Key Encryption**

On face value, since asymmetric keys are larger than symmetric keys, data that is encrypted asymmetrically is tougher to crack. However, it does not mean that asymmetric encryption should always be used over symmetric encryption. The choice of which encryption should depend on the computational burden and ease of distribution (Digicert 2015).
As mentioned, symmetric keys require less computing power and therefore operate at faster speed than asymmetric encryption. However, as the same key is used, the distribution of the key must be done in a secure manner. This makes it difficult if the other person you want to give the key to is in another country or continent.

Asymmetric encryption does not have this problem, as providing the private key remains safe, then no one is able to decrypt the messages sent. This means that the public key can be distributed freely without needing to worry who gets it. Consequently, this comes with the downside of requiring far more computing power than symmetric encryption.

In order to negate the disadvantages of both symmetric and asymmetric key encryption, most transmissions that involve encryption use both. Asymmetric encryption is used to initiate the session and to exchange a symmetric encryption key that will only be used for that session, otherwise known as a session key. As the session key was encrypted with public and private keys, it can be sent in a secure manner. As a result, communications can be exchanged using symmetric encryption for the remainder of the session as it is faster (Richardson and Thies 2012).

**Should NVQ use Asymmetric or Symmetric Key Encryption?**

As it is recommended that NVQ use TLS/SSL, they will therefore utilise both asymmetric and symmetric key encryption, as TLS/SSL uses both methods of encryption in order to remain secure. Digicert (2015) describes how this occurs using the diagram below.

![Diagram of SSL/TLS encryption process](image)

1. Server sends a copy of its asymmetric public key.
2. Browser creates a symmetric session key and encrypts it with the server's asymmetric public key.
3. Server decrypts the asymmetric public key with its asymmetric private key to get the symmetric session key.
4. Server and Browser now encrypt and decrypt all transmitted data with the symmetric session key. This allows for a secure channel because only the browser and the server know the symmetric session key, and the session key is only used for that session. If the browser were to connect to the same server the next day, a new session key would be created.

**References**

## Appendix 2: Grading criteria

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<tr>
<th>Mark</th>
<th>Individual portfolio (60% of module)</th>
<th>Working with others (10% of module)</th>
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<tr>
<td>Fail (0-29)</td>
<td>Inadequate level of engagement with the tasks to demonstrate appropriate knowledge or skills.</td>
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| Narrow fail (30-39) | At least three handouts produced, but largely superficial.  
|                | Some attempt at evaluation of tools/techniques used.                                                 | On time for some meetings and presentations completes most work but lacks reliability. |
| Pass (40-49)  | At least three handouts produced providing most relevant key points and mostly accurate summaries of topics researched with some references.  
|                | Some explanation of application of research to network design and evaluation of tools/techniques used. | Usually communicates quickly with others if problems attending or meeting commitments.  
|                |                                                                                                     | On time for most meetings.                   |
|                |                                                                                                     | Completes most work allocated.               |
|                |                                                                                                     | Contributes to most presentations or demonstrations  
|                |                                                                                                     | NB, Students can be excluded from teams for not meeting these requirements. |
| Satisfactory (50-59) | At least four handouts produced providing most relevant key points and accurate summaries of topics researched with references.  
|                    | References are mostly formatted in Harvard standard.                                                 | Considered reliable by teammates.            |
|                 | Clear relevance of application of research to some aspects of network design and evaluation of some tools/techniques used | Almost always communicates quickly with others and renegotiates if problems attending or meeting commitments.  
|                 |                                                                                                     | Contributes to all presentations/demonstrations. |
|                 |                                                                                                     | Shares work with others in timely way.       |
|                 |                                                                                                     | All work is posted on Blackboard             |
| Very good (60-69) | At least four handouts produced providing most relevant key points and accurate summaries of topics researched with references.  
|                    | Application of findings to PBL case is clearly demonstrated.                                       | As satisfactory pass and on time for almost all meetings.  
|                    | All references in Harvard standard.                                                                 | Completes all work as agreed to acceptable standard. |
|                 | Clear relevance of application of research to most important aspects of network design and evaluation of key tools/techniques used |                                                                                      |
| Excellent (70-84) | As very good pass and handouts are thorough, concise and relevant.                                   | As very good pass and shows initiative in some areas of work.                         |
|                 | Several high quality references used appropriately.                                                |                                                                                            |
|                 | Systematic evaluation of research and tools/techniques used some discussion of alternatives.      |                                                                                            |
| Outstanding (85-100) | As excellent pass with critical evaluation of alternatives provided.                               | As excellent and shows initiative and leadership in solving problems/helping others.   |
|                | Portfolio commentary provides critical analysis of research and tools/techniques                  |                                                                                            |
### Team elements of PBL scenarios

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<th>Mark</th>
<th>PBL2 report (3%)</th>
<th>PBL3 report (7%)</th>
<th>PBL4 team demo (20%)</th>
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<td>applied correctly.</td>
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<td>linked to all requirements.</td>
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<td><strong>Outstanding (85-100)</strong></td>
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<td>demonstrates areas of solution</td>
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<td>and work correctly</td>
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