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Creating an assessment and feedback strategy for problem based learning chemistry courses

Dylan Williams
University of Leicester, UK
For correspondence, please contact: *dylan.williams@leicester.ac.uk*

Dylan P. Williams is a teaching-dominant lecturer at the University of Leicester. Dylan's research is focused on innovative approaches to chemistry teaching, primarily Context/Problem Based Learning (C/PBL).

Introduction

Since the first implementations of Problem Based Learning (PBL) in medical teaching in the 1960s, the pedagogical approach has become increasingly popular in the teaching on physical science programmes. PBL approaches to learning and teaching are based on student-focused enquiry with a particular emphasis on the development of high level skills, including the application of abstract discipline specific knowledge to vaguely defined interdisciplinary research questions and, the ability to communicate the findings of a project to a range of diverse audience types. A PBL-based assessment and feedback strategy was developed for chemistry students at the University of Leicester, based upon a cyclic process which integrated formative assessment and feedback throughout the problem solving process and providing students with regular opportunities for self-reflection. This case study examines and evaluates the success of this initiative.

Background

Problem Based Learning (PBL) is a student-centred teaching and learning approach which usually involves small groups of students (group sizes vary but are often between four and eight (Savery & Duffy, 1995; Lohman & Finkelstein, 2000) working on the solutions to open-ended problems based on real-world scenarios (Engel, 1997; Raine & Symons, 2005). Basing PBL problems on real-world scenarios creates a context for the learning experience which refers to the environment within which the skills and knowledge will ultimately be applied (Honebein, Duffy & Fishman, 1993).

It is widely believed that PBL originated in medical science degree courses in North America in the 1960s (Woods, 1996; Boud & Feletti, 1997). Since then, the approach has become increasingly popular in other geographical regions and other disciplinary areas (Savery & Duffy, 1995). PBL was first used in the teaching of chemistry in UK Higher Education Institutions in the early 21st century at the Universities of Hull and Plymouth (Belt, Evans, McCreedy, Overton, & Summerfield, 2002). In recent times an increasing number of other chemistry courses have adopted the approach (Williams, Woodward, Symons & Davies, 2010). Motivations for adopting PBL approaches include the need to update chemistry curricula to meet the requirements of the increasingly diverse pre-University educational backgrounds of 21st century students (Walker, 2009), the increasing demands on universities to provide active learning experiences based on recent developments in educational research (Freeman, Eddy, McDonagh, Smith, Okoroafor, Jordt, & Wenderoth, 2014) and the need to better equip chemistry graduates with the professional skills required in the modern chemistry workplace (Royal Society of Chemistry, 2009).

Addressing the skills gap
One of the primary criticisms of UK chemistry degrees from graduate employers and employees in the early 21st century was the lack of emphasis on developing problem solving skills, research skills and transferable skills (ibid, 2009). Research showed that a significant number of graduate employees felt that their chemistry degree education had focused on specific disciplinary skills which may have been of limited use to them in their careers whereas they felt that transferable skills that benefited the majority of graduate roles had not been developed to a satisfactory extent (Hanson & Overton, 2010).

PBL was identified as a potential mechanism for enhancing the training of employability and transferable skills in chemistry degree programmes (Kelly & Finlayson, 2007). Enhancing the development of transferable skills using PBL allows instructors to create learning experiences which are strongly rooted in discipline-relevant contexts allowing students to see the relevance of their learning to their professional development. PBL tasks require students to take ownership of the learning process, to work as part of well-coordinated teams and to develop a reflective approach to skills development.

PBL problems are usually structured in such a way that students are not given enough information to solve the problem without conducting further research (Raine & Symons, 2005). The PBL process facilitates social learning by requiring students to collaborate in groups on the development of agreed group solutions to problems (Raine & Symons, 2005). Many PBL approaches facilitate an iterative approach to problem solving (Clougherty & Wells, 2008, Williams et al., 2010) where one cycle of research might highlight deficiencies in the group's original research plan which have to be addressed before the problem can be solved.

The principle motivation for providing students with this type of open-ended learning experience is to ensure better alignment of the student experience with the reality of the challenges that employees working in the relevant disciplinary area face on a day to day basis.

Assessing PBL problems
Designing educational experiences that use the PBL approach requires instructors to think carefully about the modes of assessment used (Overton, Byers, & Seery, 2009). Given the problem-solving nature of this type of learning experience, assessment strategies have to recognise the importance of the problem-solving process in addition to the quality of the final deliverable (Tai & Chan, 2007). One of the key motivations for developing learning experiences based on PBL is the development of research, communication and interpersonal skills so assessment strategies have to be developed which can support the development of these skills.

During PBL contact sessions the problem solving process is facilitated by an academic member of staff or a trained postgraduate or postdoctoral researcher (Kolmos, Xiangyun, Holgaard, & Jensen, 2008; Williams et al., 2010). During contact sessions the facilitator is able to provide participants with 'live' formative feedback on their problem solving approach and they encourage students to reflect on their own skills development as they work on the problem (Wilkie, 2000). Groups can use discussion with the facilitator as a basis to improve their approach to problem solving and to audit their skills development and set targets for further development. The role of the facilitator in PBL learning environments is to support the student learning experience so discussion focuses on the process of arriving at the solution rather than the end product.

The group problem solving process typically leads to a final summative assessment (sometimes referred to as a deliverable (Williams et al., 2010)) which is usually assessed by the facilitator or another academic although it is known that some implementations make use of peer-assessment to conduct this evaluation (Tan & Keat, 2005). The nature of the deliverable may be dictated by the type of problem, the scenario and the primary aims of the specific PBL implementation. As PBL is often used to help students develop the kind of skills they may rely on later in their careers, the development of an authentic assessment approach is important (Waters & McCracken, 1997; Hanna, 2002; Barber, King, & Buchanan, 2015). The deliverable should mimic the type of output that the problem would have if the participants encountered it in a professional context rather than an academic one. In degree programmes which lack a single career path, a range of different types of problems may be used in order to highlight some of the types of roles that graduates of that programme may expect to find themselves in (e.g. a UK natural sciences programme includes a courtroom scenario assessment which is relevant to careers in forensic science, the police or criminology) (Raine, 2015).

Table 1. Examples of two PBL problems which have been developed for University of Leicester chemistry students.

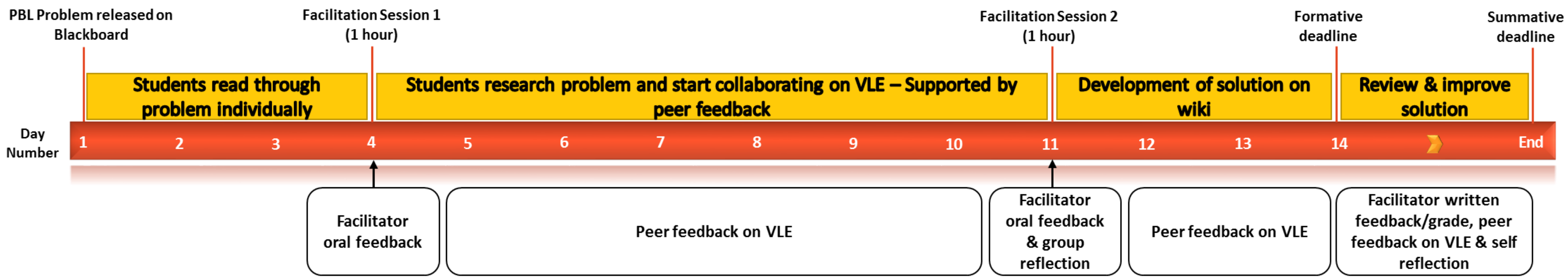
	The Chemistry of Energy	**Chemistry and Food Security**
Nature of problem	Students work on the development of a sustainable energy strategy for a small EU nation by considering a number of new technologies and the specific requirements of the nation	Students are placed in the scenario of summer interns at an analytical laboratory investigating adulteration of food and drink
Level	Undergraduate year two	Undergraduate years one or two
Disciplinary areas	Nuclear chemistry Organic chemistry Physical chemistry Engineering Chemistry-physics interface (e.g. magnetic materials)	Analytical chemistry Organic chemistry Polymer chemistry Chemistry-biochemistry interface
Deliverables (summative assessments)	Press release Press conference (15 mins as presenters, 45 mins as member of press) Writing a research paper	Formal reports Plans of laboratory investigations Building a website/wiki Delivering a business pitch

PBL activities developed for chemistry students at the University of Leicester are typically based on interesting scenarios which highlight the relevance of chemistry to society (see table 1). The problems have also been designed to help students see the interdisciplinary nature of much of the work conducted by professional chemists.

PBL assessment & feedback at Leicester

The Leicester approach to PBL was designed to provide a continuous cycle of formative feedback which supports the problem solving process. A typical Leicester PBL problem runs over a two week period (see Figure 1) with time after that period to make further edits to the problem solution. The PBL cycle includes two one hour contact sessions (known as 'facilitation session') and two deadlines: one at the end of the two week cycle where students receive a formative grade and feedback and another at the end of the module where students receive a summative grade and feedback.

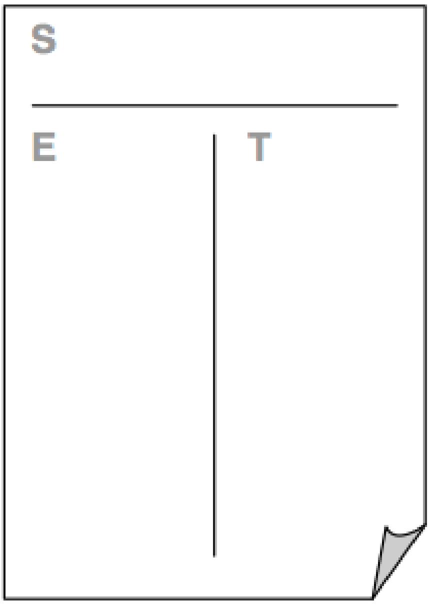
Figure 1. Timeline of PBL activities of a typical Leicester PBL problem. A PBL module would consist of a number of problems of this type.



Assessment and feedback in contact sessions

The first task that groups (the typical group size is five to six) must complete when working on a new problem is to create the first draft of an agreed problem solving strategy. At the University of Leicester, the development of a problem solving strategy is scaffolded by a form known as the **SET** sheet (Figure 2). The SET sheet includes sections for the agreed group **S**ummary of the problem, a list of any **E**xisting skills and understanding which is relevant to the problem and a list of **T**hings that must be researched and worked on in order to solve the problem (Williams et al., 2010; Williams, 2015). The group's facilitator provides oral feedback on this problem solving strategy in the first session and reminds the group to keep updating the document throughout the problem solving process (e.g. by continuously updating the group's agreed summary of the problem so as to keep it 'live'). Providing oral feedback throughout the problem solving process is a very important part of the facilitator's role as students participating in PBL experiences may have little previous experience of similar situations. Facilitator oral feedback typically focuses on aspects of group organisation, planning and communication but can also include some feedback on discipline specific matters relevant to the problem but must never circumvent the student-centred nature of the approach by directing students to a solution.

Figure 2. The layout of the 'SET' sheet that students use to help plan the problem solving process. The 'S' represents 'Summary of the Problem', the 'E' represents 'Existing Knowledge Related to Problem' and the 'T' represents 'Things to Research'.



Assessment and Feedback between Contact Sessions

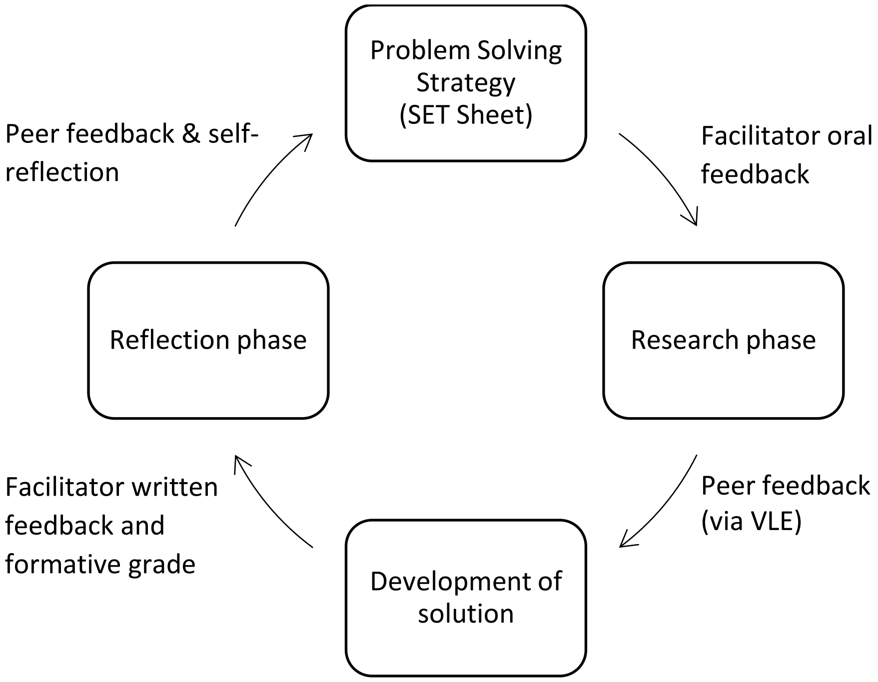
Once students have created their initial draft of the problem solving strategy, they are expected to research the problem, share ideas and start creating a preliminary solution (this is known as the 'Research phase'). As much of this phase of the process takes place outside of facilitated contact sessions, an online environment was designed which was hosted on the University of Leicester's Virtual Learning

Environment (Blackboard). This online environment provides a platform for students to interact with each other remotely (a group discussion board), to develop a solution to the problem (a group wiki function) and to provide peer feedback and receive formative feedback from facilitators (using the ‘comments’ feature which was integrated into each page of the group wiki). Between the first two facilitation sessions, students are encouraged to provide peer feedback.

Following the second facilitation session, students complete their initial solution of the problem based on their group discussion and the oral feedback they receive from the facilitator in the second session (this is known as the ’Development phase’). Groups receive formative written feedback on their wiki pages from their facilitator the following week. The feedback focuses on the rigour of the problem solving approach, the structure of the draft solution to the problem, the presentation of the solution and the scientific validity of the solution that has been developed. The feedback left by the facilitator includes an indicative grade which shows students the standard of their draft solution. Summative assessment takes place at the end of the module. This allows groups to reflect on their approach to the problem (the ‘Reflection phase’) and repeat the problem solving cycle (see Figure 3) to improve their solution based on the formative feedback and grade.

Group wikis were used as a platform for student collaboration as they provide a virtual collaborative workspace which can be used to facilitate group collaboration and social learning (McDonnell, 2014; Kristian, 2015). Students were given an introductory session on using wikis and were provided with a short user guide. Students were told to provide peer feedback on the group wiki pages. Students were given some guidance on how to write peer feedback (e.g. comments on presentation, the quality of the scientific discussion, the viability of the solution, etc.) and were told to write this feedback in the ‘Comments’ section of the wiki pages. The group discussion board was provided as a platform for students to exchange ideas and ask questions to other group members. Groups are informed that their facilitator will not contribute to the discussion board unless the group specifically requests the facilitator’s input. It has been observed that use of the discussion boards has declined since their initial introduction in 2007. When questioned about this, students have fed back that they prefer to use other social media tools (e.g. Facebook groups) to collaborate remotely. Collaboration using social media tools has the advantage that it allows students to use the platforms they are already familiar with and can access in a way that suits them (e.g. on smart phones and tablet devices) but it has the disadvantage any content shared via this platform exists beyond of the control of their institution.

Figure 3. The cyclic nature of a typical Leicester PBL problem. The boxes represent the different components of working on a PBL problem and the annotations on the arrow show how each stage is supported by feedback and reflection.



Assessing the Problem Solving Process

Providing an effective summative assessment for the problem solving process (as opposed to the final deliverable) has proved to be a difficult task. Previous studies have indicated that peer and tutor generated process marking can be of limited validity (Swanson, Case, & van der Vleuten, 2001). A facilitator marking model was adopted at Leicester where students were awarded individual marks for their contribution to the problem solving process. This ultimately proved to be unsuccessful due to difficulties in rating student performance in tasks which were largely conducted outside of the scheduled contact time. Tutor based marking was subsequently removed but students continue to receive formative feedback from their facilitator on their approach to the problem solving process based on observations of how students work together as a team, the quality of the records kept by the group (e.g. the ‘SET’ sheet) and the level of collaboration which takes place on the VLE (which can be easily monitored by the facilitator).

In order to ensure the marks are fairly distributed to individual members of the group, each individual group member is asked to complete a peer-review survey at the end of each PBL module. Students are introduced to the peer-review process in a presentation at the start of a contact session. The presentation outlines the purpose of the peer-review process and informs them about how the process works. This guidance is supported by written instructions which are available on the VLE. The survey asks students to rate each other’s levels of contribution but does not ask them to directly award a mark. The group mark is then scaled for each individual student based on the responses to the survey. Students have responded positively to this mechanism for rewarding different levels of contribution.

Student reflection on skills development
Previous studies have indicated the effectiveness of the PBL approach in developing metacognitive awareness levels amongst students (Downing, Kwong, Chan, Lam, & Downing, 2009; Tosun & Senocak, 2013). As the use of PBL forms part of a broader departmental strategy to facilitate the development of transferable skills and to give students experience of applying their understanding of the subject to real-world problems, students are required to complete a skills audit during each PBL module and a group based reflective discussion in every facilitation session. Students are introduced to the principle of reflection in the opening PBL presentation. The students are informed that reflection forms an integral part of the learning process. The reflective discussions are supported by each group’s facilitator so students gain confidence in evaluating their own performances in the PBL tasks. The skills audit takes the form of an online questionnaire in which students rate their confidence in a range of different transferable and discipline-specific skills and to state which skills they feel they have developed the most during the module. The skills audit questionnaire builds on the reflective discussions that students have at the end of every PBL session. The purpose of this exercise is to encourage student reflection on skills development so they can identify their strengths and consider where further development is required. The data generated by this activity is also used by staff to identify areas where students are lacking confidence in order to customise later learning activities to provide the skills development opportunities that students need.

Evaluation
As one of the primary aims of the Leicester assessment strategy was to improve student confidence in a range of transferable and discipline-specific skills, questionnaires were designed to measure these confidence levels. The responses of year one students to the questions on some selected skills in the 2015-16 questionnaire (53 responses) are shown in Figure 4. Student confidence levels in all skills are generally good with over 60% of students reporting that they were either confident or very confident in all skills shown in this figure. Over 90% of students recorded a confident or very confident response for both ‘Working in a Team’ and ‘Problem Solving’. Confidence levels were poorest in the response for ‘Scientific Method’ where only 63% of respondents recorded confident or very confident responses. The student emphasis on general transferable skills development was reinforced in a question which asked students to list the three skills which they felt they had developed the most as a consequence of completing the PBL module. The most popular responses to this question were ‘Communication’ and ‘Teamwork’ skills. A relatively small number of students listed discipline specific skill (e.g. ‘Scientific method’ and ‘Data analysis’). A qualitative summary of the relative emphasis of the different skills listed can be seen in the Wordle in Figure 5.

Figure 4. Responses to the skills reflection questionnaire from the 2015-16 academic year. The total number of responses = 53. Absolute numbers of respondents shown at the top of each bar.

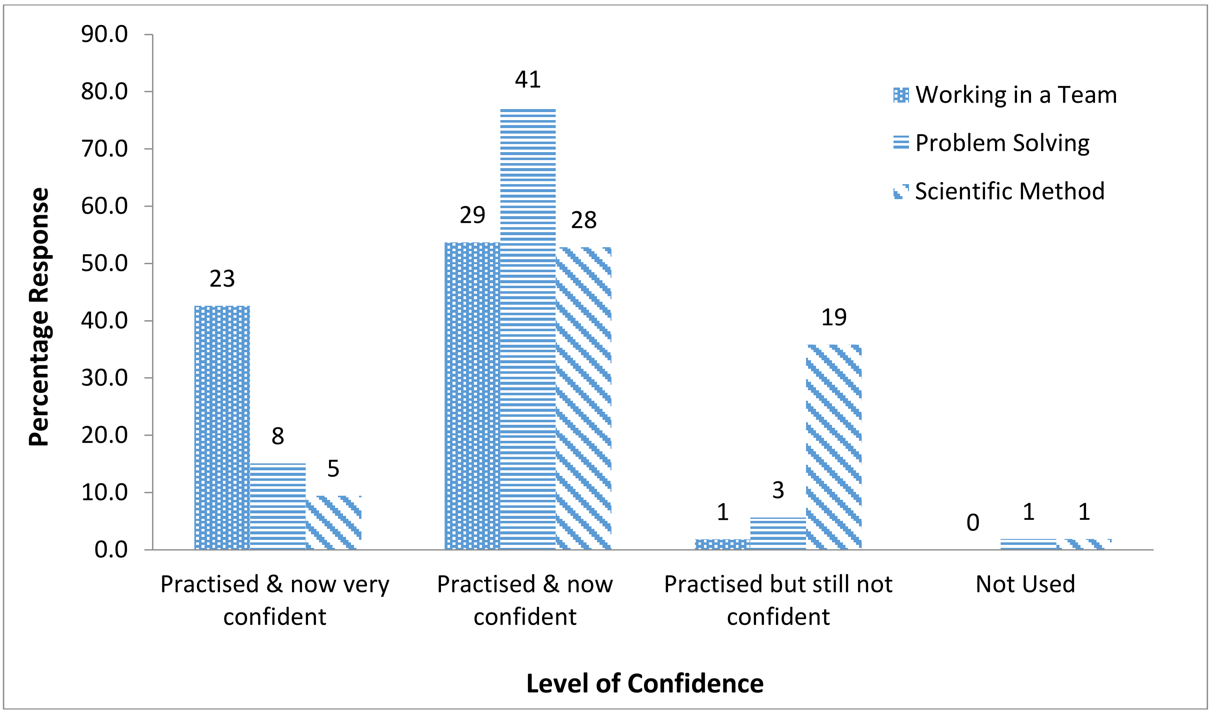


Figure 5. A Wordle of student responses to a question which asked them to state the three skills they developed the most by completing a Leicester PBL module.

The student responses to this questionnaire suggest that the learning experience may be more effective at developing student confidence in transferable skills than it is in developing discipline-specific skills with some student comments supporting this (e.g. '*Experimental design should be expanded a bit more*'). Student comments were positive about the development of transferable skills (e.g. '*helped me develop some core social skills required in the scientific field and helped me establish a better understanding of what it looks like to work as a research chemist*' and '*It helped me to be independent*'). It is likely that the levels of confidence in these skills reflect the structure of the PBL problems and the emphasis placed on them in the facilitator feedback. The results of this evaluation have informed the approach to designing new PBL activities and facilitator support at Leicester. New problems incorporate more opportunities for students to work on experimental design and devising a scientifically valid approach to a problem. Future work at Leicester will aim to measure the difference in student perceptions of core transferable and discipline-specific skills before and after PBL modules.

The current form of the assessment and feedback strategy has been integrated into the teaching of the Chemical Principles module (year one, approximately 120 students per year) since the start of the 2014-15 academic year. When comparing the mean module mark before and after this version of the strategy was introduced (table 2), there does appear to be some improvement in student performance. It should be highlighted that the module includes elements which are not taught by PBL (flipped lectures, small group tutorials and problem classes are also used).

Table 2. Mean marks for Chemical Principles module at the University of Leicester in the period 2010-2016

	2016	2015	2014	2013	2012	2011	2010
Chemical Principles mean mark	59%	60%	59%	56%	53%	54%	47%

Conclusion

The development of an assessment strategy which supports the cyclic nature of a PBL problem has allowed chemistry undergraduate students at the University of Leicester to achieve high levels of confidence in transferable skills such as problem solving, teamwork and communication skills. Further work on problem structure and facilitator support may allow the approach to support the development of greater levels of confidence in discipline-specific skills such as experimental design and scientific method.

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