Teaching Chemistry in Higher Education

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9 Context- and problem-based learning in chemistry in higher education

Dylan P. Williams
Department of Chemistry, University of Leicester
dpw10@leicester.ac.uk

This chapter will provide an overview of the introduction of context- and problem-based learning (C/PBL) approaches in chemistry teaching in the UK and Ireland. This will be illustrated using examples from the University of Leicester's introduction of these approaches in the early stages of the chemistry degree programmes at Leicester. The impact of this initial implementation was measured through student interviews and comparison of student performance with previous years. Later implementations used problems designed by multidisciplinary author teams based at Leicester. The impact of these implementations on student perceptions of skills development was measured inspired by the work of Overton and Hanson.

The introduction of C/PBL at Leicester helped improve students' awareness of the importance of transferable skills development without negatively influencing performance in chemistry assignments. Ongoing research and evaluation has shown that, as part of an employability strategy, C/PBL activities have contributed to high employability levels of Leicester chemistry graduates and have contributed to improvements in student perceptions of skills development. This work has created a suite of C/PBL resources which are freely accessible via the Royal Society of Chemistry's Learn Chemistry platform. The insight provided by this work has also helped academics at other institutions adapt these resources to suit their own local contexts. Guidance is provided in this chapter on how this can be achieved.

Influence of Professor Tina Overton
Tina was instrumental in introducing C/PBL approaches in the UK and Ireland. Some of Tina's published resources (such as A Dip in the Dribble and The Pale Horse) are amongst the first chemistry-based C/PBL published outside of North America. Tina was instrumental in the introduction of the approach at other institutions and went on to explore how the approach could be further developed (for example by researching Dynamic PBL approaches and Internationalisation in C/PBL).

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Introduction

Development of key workplace skills in chemistry undergraduates

Research in the early years of the 21st century revealed the existence of a disconnection between the skills that chemistry graduates were leaving university with and those that were most commonly required by chemistry graduates in their professional roles (Overton and Hanson, 2010). Graduates and graduate employers reported the underdevelopment of a number of key workplace skills including communication skills (written and oral), organisational skills, the ability to solve open ended problems and the ability to work effectively as part of a heterogeneous team with different skills sets and experiences (Overton and Hanson, 2010). At the same time, there were calls to develop new teaching and learning approaches that would allow the development of constructivist learning experiences for undergraduate chemists (Eilks and Byers, 2010). Constructivism is a learning theory that stresses the active nature of learning processes. Learners are said to construct knowledge by making meaning of new ideas in the context of their previous understanding or experience (Bodner, 1986).

In order to address these demands, a variety of different educational approaches were developed including innovative open-ended approaches to practical work (Graham *et al*., 2008, Ram, 1999), team based learning (TBL) (Evans *et al*., 2016) and problem and context based learning (C/PBL) approaches (LaForce *et al*., 2017, Overton, 2007).

Context- and problem-based learning

Context-based learning (CBL) approaches to learning chemistry are based on the reversal of conventional approaches to learning the subject; that is, starting with submicroscopic and representational domains (Chittleborough and Treagust, 2007, Gilbert and Treagust, 2009, Taber, 2013). Instead they start with an engaging context to drive the student learning experience (Overton, 2007). Problem-based learning (PBL) is a closely related approach which presents CBL-style contexts in the form of open-ended, ill-defined problems (Overton, 2007). Students typically work on these problems in small teams and the assessment of these types of problems can take a diverse range of forms (Raine and Symons, 2005). Due to the parallels between these two approaches, they are often discussed together. For the rest of this chapter, the term context- and problem-based learning (C/PBL) will be used to describe learning and teaching approaches that can be classified by either of these definitions.

The first reported use of C/PBL in higher education occurred in medicine teaching in Canada and the United States in the 1960s (Wood, 2003, Woods, 2000). The approach was particularly well suited to medicine due to the vocational nature of this degree programme (Wood, 2003). The implementation of the approach in other discipline areas slowly gained momentum in the later stages of the 20th century, such as in engineering education (Bédard *et al*., 2012). The C/PBL approach can facilitate the integration of workplace skills development in the curricula of university level degree programmes (Carvalho, 2016, Williams and Lo Fan Hin, 2017). As a consequence of this broad applicability, the approach has recently been exploited in degree programmes in a range of STEM (science, technology, engineering, and mathematics) disciplines (LaForce *et al*., 2017).

Context- and problem-based learning with chemistry undergraduates

The use of C/PBL approaches in the teaching of undergraduate chemistry had already been reported in North America by the start of the 21st century (Dods, 1996, Ram, 1999). C/PBL approaches tend be student centred (Maurer and Neuhold, 2012) with an emphasis on the process of arriving at a solution to an open-ended problem which is often based on a scenario of relevance to professionals in the specific discipline area (Raine and Symons, 2005). The adoption of C/PBL approaches in chemistry has facilitated the integration of team activities in chemistry curricula (most implementations involve students working in small teams of between 4–6 members). Previous research had also shown that adoption of these approaches can enhance student engagement in their subject area (Belt, 2009, Blumenfeld *et al*., 1991, Bredderman, 1983).

The assessment of these activities is typically aligned with the professional expectations of graduates in the discipline area. The C/PBL approach can be a particularly effective way to embed the development of communication and organisation skills as well as professional values in the core chemistry curriculum and to give students the opportunity to gain experience of working in heterogeneous teams in a chemically relevant context. Student learning in C/PBL sessions is typically facilitated in a way that supports their development and gives them the confidence to develop their own innovative solutions to problems (Raine and Symons, 2005).

The earliest documented implementations of the C/PBL approach in chemistry teaching in the UK and Ireland occurred in the early 21st century (Belt *et al*., 2002, Kelly and Finlayson, 2007, Summerfield *et al*., 2003). A Royal Society of Chemistry (RSC) funded initiative resulted in the development of a series of open-ended case-studies based on themes including industrial chemistry (The Titan Project), environmental chemistry (A Dip in the Dribble), the role of chemistry in sports science and forensic science (The Pale Horse) (Overton, 2007). These resources remain freely available on the RSC's Learn Chemistry platform (Royal Society of Chemistry, 2018). By using engaging contexts focused on these professionally relevant contexts, these early problems succeeded in supporting student learning by giving them an opportunity to think carefully about how the subject applies in areas of relevance to society (Overton, 2007). The open publication of the resources developed in this early stage of implementation catalysed an increase in interest in the approach, which ultimately resulted in further RSC funded initiatives to develop a library of C/PBL resources that could be used by practitioners throughout the sector. The success of these early implementations of C/PBL in chemistry teaching in the UK has led to a number of innovative adoptions of the approaches. These include the development of dynamic approaches to PBL which allow a team's route through a PBL problem to be defined by decisions made at various stages of the problem solving process (Overton and Randles, 2015).

Initial implementations of C/PBL at Leicester

The first implementations of C/PBL approaches in physical science teaching at Leicester were focused on the degree programmes offered by the Department of Physics and Astronomy (Raine and Symons, 2005). After initial success in the physics degree programmes, a new interdisciplinary science degree programme, iScience, was established which adopted a research-led teaching philosophy. This research-led approach was facilitated by a series of modules based on C/PBL approaches. These modules were truly interdisciplinary in nature (the problems required students to think carefully about the overlaps between the different core science subjects and to apply these ideas to authentic research questions) (Raine and Symons, 2005). Much of this early work on the physics and iScience degree programmes inspired the later implementation of C/PBL approaches in chemistry at Leicester.

Methods

Setting for the C/PBL development and implementation

C/PBL resources have been used throughout the undergraduate chemistry degree programmes at the University of Leicester. The chemistry degree programmes typically recruit up to 120 students per year.

The entry requirements for the chemistry degree programme at Leicester means that it can be assumed that students join the programmes with a good entry level understanding of the subject (by having a good A Level grade in the subject or a suitable equivalent). Some C/PBL resources have been developed for use with the entire cohort whereas other, more specialised, resources may only be used for students enrolled on particular modules (for example students on our Pharmaceutical Chemistry degree programme have a number of custom modules which are not taken by chemists studying our other degree programmes). A summary of C/PBL resources developed for chemistry students at Leicester is shown in Table 1.

Table 1: C/PBL resources developed for chemistry students at Leicester

Chemistry of Energy	Chemistry and Food Security	Chemistry's Frontiers	Learn on the Move
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	Students work on three short problems designed to highlight the interdisciplinary nature of research in nanotechnology, chemical biology and geochemistry	Students must enter a university competition to produce and evaluate a learning resource for students in the opening stages of their degree programme
Level			
Year 2	Year 1–2	Year 1–2	Year 1 (induction)
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	Chemistry's interfaces with physics (nanotechnology), geology and biology	Students choose their specific area of focus but the chosen area must align with a topic from a Year 1 General Chemistry module
Deliverables			
Press release Press conference Writing research paper Developing a model for calculating estimated CO_2 output of new power generating approaches	Formal reports Plans of laboratory investigations Building a website/wiki Delivering a business pitch	Radio interview Museum guide Experimental plans	Submission of developed learning resource Written report describing design and evaluation processes as well as key findings

Running a C/PBL induction

Research has stressed the importance of providing students with a suitable introduction to C/PBL at the start of a course (Jansson *et al*., 2015). An induction activity called *Learn on the Move* is used to introduce all new chemistry students at Leicester to the C/PBL approach as well as to the other members of the teams they will work with on other activities (Williams, 2017). This activity takes the form of a design competition which requires teams to design, develop, and evaluate a small educational resource that could be used by first year students in the opening semester of a chemistry degree programme (Williams, 2017). The discussion trigger questions that teams were asked to consider were designed to encourage students to think carefully about the different types of learning experiences they had previously encountered and to think about what had been particularly effective for them and why. Teams had to think carefully about how to produce a resource that met the learning needs of a diverse target audience and the limitations imposed on them by the nature of the activity. Teams were told that the resource had to be portable enough to be used on the bus commute from the halls of residence to the central campus and had to allow users to have a meaningful learning experience on the timescale of the 20 minute journey.

Example of how to implement C/PBL: *The Reality of Nutrition*

The implementation of C/PBL approaches will be discussed in the context of an example activity *The Reality of Nutrition*. The following section will include a suggested time plan for this activity along with discussion of the practical steps that need to be taken to prepare, run, and assess the activity. The full activity (including a detailed tutor guide) has been published as an open educational resource as part of the RSC's Learn Chemistry platform (Royal Society of Chemistry, 2018).

Context of The Reality of Nutrition

The Reality of Nutrition is a 20-hour long student activity which involves up to 3.5 hours of contact time and up to 17 hours of group work. *The Reality of Nutrition* was designed to address inaccurate and negative portrayals of chemical biology in the popular media. The activity was designed to provide Year 1 or 2 chemistry students (with a limited experience of biology) with learning experiences at the frontier of the chemical and biological sciences. The activity is based around problems that require students to critically evaluate the presentation of scientific topics in the media.

The scenario

The activity is divided into two related sections. The first section requires students to proof-read a guest editorial in a nutrition and health journal published by a learned society. The guest editorial is written by a nutritionist who has achieved fame as television presenter. The editorial has been seeded with a number of factual inaccuracies and questionable statements. The students must engage with the peer-review process and decide how to communicate the decision back to the guest editor. The next step of the activity depends on the peer-review decision that the students make: the chief editor will require that students write a two page article about the structure and function of proteins for the next issue if they choose to publish the guest editorial in its current form. If the students choose to correct the editorial they will need to provide the guest editor's legal team with a full justification for the changes. If the students decide that the guest editorial does not meet the standards of the journal, they will need to write a full explanation of why this is the case to the chief editor.

The second section of the problem is based on a radio interview given by the same media nutritionist involved in the previous section. The radio station was concerned about the accuracy of some of the statements made in the interview so it has invited representatives of the learned society to appear in the next episode of the programme to respond to questions from listeners. This assessment takes the form of a role-play where students participate in a radio interview. A suggested time plan for running the activity is shown in Table 2.

Preparation for the activity

Table 3 presents an overview of the tutor preparation required in advance of running the activity. The first stage is to ensure that all programme and module documentation is updated to reflect the new teaching and learning methods, the new assessment approaches and any new intended learning outcomes. This may need to be done a long time in advance of the start of the activity (the precise timing will be defined

Table 2: Suggested time plan for *The Reality of Nutrition*

Topics	Transferable Skills	Assessment	Feedback
Week 1 (60–90 minutes)			
Proteins Enzymes Enzyme Kinetics	Team working Group discussion Independent learning Critical thinking Decision making Written communication	A letter of response to the editor giving details of the decision made regarding the publication of the editorial. A two-page magazine article for publication in a magazine read by biochemists at a range of levels: from interested A Level students to practicing chemistry, biology and biochemistry researchers. This response should include an analysis of the kinetic data provided.	In session: For students who publish the editorial including some or all of the errors — a copy of the email from the chief editor which includes the complaint from the reader complaint. For students who correct Dr Sally's editorial — a copy of the email from Dr Sally's legal team. Before next session: Receive brief written formative feedback on article prior to the next session.
Week 2 (1) (60–90 minutes)			
Nucleic acids and DNA Fatty acids and lipids Polysaccharides and carbohydrates	Group discussion Independent learning Planning Oral communication Time management	To take place in next session. Students should use part of this session to prepare material for the radio interview (either in the form of a podcast or a live interview given in front of an audience of peers.	In session: Provide verbal feedback on the students' group debate/practise interview. Encourage the students to answer questions which allow the students to correct statements made by the interviewer.
Week 2 (2) (20–30 minutes)			
Nucleic acids and DNA Fatty acids and lipids Polysaccharides and carbohydrates	Team working Oral communication Time management	A mock radio interview to respond to the information provided by Dr Sally in the previous programme (either in the form of a podcast or a live interview given in front of an audience of peers).	Students receive formal feedback on the podcast/interview.

Table 3: An overview of the key steps that need to be taken before running a C/PBL activity

Activity	Timescale	Details
Update programme and module documentation	Timescale defined by local institution	Ensure that the learning and assessment activities are accurately described in module and programme documentation and intended learning outcomes are updated to align with the new activities.
Arranging suitable learning spaces and timetable slots	Timescale defined by local institution	Flat learning spaces are required that can be configured in a cabaret format to allow students to work in teams of 5–6. Ensure that times and locations of sessions are clearly communicated to students.
Train facilitator teams	Within a month of the start of the activity	Provide facilitators with an overview of the aim of the learning experience and a definition of the format. Run an example C/PBL experience. Ask facilitators to reflect on the experience and contrast this with their other learning experiences. Provide feedback to facilitators.
Create a dedicated space on the VLE and upload all relevant documentation	In advance of C/PBL sessions — this will need to be updated throughout the activity	Typically, documentation is released on a session-by-session basis so setting up timed release of relevant documentation is helpful.

by your institution's regulations). Once these changes have been approved by the institution and the relevant documentation has been updated, suitable flat learning spaces need to be booked and the details need to be embedded in the timetable and publicised to students. We have found that flat learning spaces that can be configured in a cabaret format to allow students to work in teams of 5–6 works well. We give careful consideration to how many teams can effectively work in a learning space. This may require some experimentation but the primary aim is to ensure that noise levels are sufficiently low that teams can effectively discuss their solution to the problem.

In order to prepare staff and postgraduates for C/PBL facilitation, a training programme was developed that emphasised the differences between C/PBL facilitation and other forms of teaching (such as knowing when not to intervene in student planning and discussion). This was achieved by developing an introduction to the teaching approach delivered by a member of academic staff experienced in the approaches. This was followed by a hands-on activity whereby trainee facilitators were assembled into a C/PBL team and asked to work through an unseen problem of the type used in the course (we typically use a part of a problem published on the Learn Chemistry platform). The trainees were then asked to reflect on the experience and to consider how best to apply this experience in supporting student learning. This reflection process was supported by a discussion with experienced facilitators who provided feedback to the trainees. In the period leading up to the start of the activity (typically one to two weeks before the start), student documentation is made available on the virtual learning environment (VLE).

Running C/PBL sessions

The Reality of Nutrition includes two contact sessions (60–90 minutes) for teams to plan and discuss the problem solving process in small teams. A suggested structure for a 60 minute session used to open a C/PBL activity is shown in Table 4.

Table 4: Suggested structure for a 60 minute session to open a C/PBL activity

Timings	Activity
0–10 minutes	Welcome students to the session and make a brief introduction if needed
10–15 minutes	Time for students to read problem and write individual summaries
15–25 minutes	Sharing individual summaries and agreeing on an overall group summary (fill in S on SET sheet)
25–50 minutes	Group discussion of problem — encourage groups to discuss what format and topic they want to focus on (fill in E and T on SET sheet)
50–60 minutes	Group reflection — what progress has been made and what remains to be done?

The contact sessions should take place a week apart in flat teaching spaces. Each of these contact sessions are facilitated by members of staff or trained postgraduates. We have found it most effective to allocate no more than two groups per facilitator. In order to support teamwork between the contact sessions, students are provided with a VLE link to the study-room booking system that allows them to book additional meeting sessions on an ad hoc basis.

In order to support students learning through these C/PBL activities, a structured problem solving approach was developed that scaffolds the learning process in a way that allows students to retain control over the creative aspects of the process. Students were provided with a number of trigger questions to prompt and focus team discussion (see Supplementary Information for a full example of a short C/PBL activity). These questions were often intentionally open-ended in order to avoid leading students to one particular end-point. In addition to this, students were asked to record notes from each group meeting using a simple three section form (Figure 1) inspired by the Maastricht Seven-Step strategy (Maurer and Neuhold, 2012). Teams start the process by writing an agreed group summary of the problem/activity (S section). Teams then document their existing knowledge and skills (E section) related to the problem (thus, requiring them to audit the collective knowledge and skills set at the start of each activity) and to list the tasks that need to be completed in order to be able to produce a response to the problem/activity statement (T section). This latter part of the form acts as a de facto action list.

The third contact session for this problem was dedicated to the assessment of the second section (radio

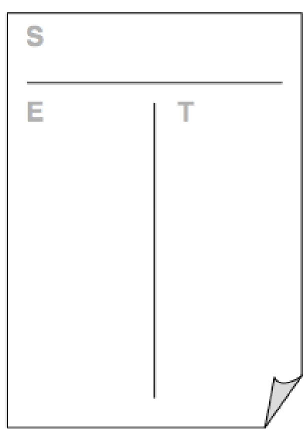

Figure 1: The three section for used to help students record their problem solving approach (Williams, 2015)

interview) of the activity. This time could be used to allow students to record the interview or to act the interview out in front of an audience.

Assessment of the activity

The assessments for all Leicester C/PBL activities are authentically aligned with the problem scenario. The assessment of *The Reality of Nutrition* was designed to support the development of subject-specific skills and knowledge alongside key workplace skills and experiences such as teamworking, communication skills and time management skills. A broader aim of this activity is to help raise students' awareness of the issues that scientists face when communicating scientific topics to a range of audience types including the media and the general public.

Marking criteria for C/PBL problems have to be flexible enough to accommodate the diverse range of submissions that students will submit. PBL activities are typically marked separately for scientific content and presentation due to the different skill sets being assessed. As example set of marking criteria for a Year 1 activity is shown in Supplementary Information. The marking criteria for all C/PBL activities are made available to students at the start of the activity.

Presentation and Discussion of Findings

Evaluation methods

During the initial implementation phase at Leicester, the impact of the C/PBL activities on engagement with other elements of the course was evaluated by comparing student performance in a number of midterm tests and laboratory assessments with performance in the two preceding academic years. This was supplemented by student and instructor interviews and questionnaires on the impact of the C/PBL experience on skills development. It was found that student performance in these activities during the first two years of C/PBL at Leicester was entirely within the expectations of the course convenors based on performance in previous years (Williams *et al*., 2010). In addition to this, the effectiveness of the approach in supporting student social integration into higher education were evident; for example, there was a positive impact on retention in the early stages of the programme (Williams *et al*., 2010).

Measuring the impact of C/PBL on perceived skills development

As described in the introduction, one of the primary motivations of embedding C/PBL approaches in the chemistry degree programmes at Leicester was to enhance the workplace skills development of undergraduate students in a subject-relevant context. At the end of the year one C/PBL module in the 2014/15 and 2015/16 academic years, students were asked to rate their confidence in a number of different skills and activities (Williams and Handa, 2016) based on their experiences in the C/PBL module. A five point Likert scale was used and the *Very Confident* and *Confident* responses were combined to allow a confidence level to be reported for each of the skills or activities (Table 5).

Table 3: Student confidence levels (expressed as percentages) after completion of year one C/PBL modules in 2014/15 and 2015/16 academic years (*n* = 114). Students were asked to rate their confidence in these areas based on their experience of C/PBL (Williams and Handa, 2016)

Oral Communication	Written Communication	Teamwork	Problem solving	Scientific method	Record keeping
77.3%	92.4%	95.8%	89.9%	68.1%	77.3%

Students were also invited to respond to free-text response questions asking them to list the three skills that they felt were developed most by doing C/PBL. Students were also asked to describe their own personal development during this module. The most common responses to these question on skills development were in agreement with the responses to the Likert-scale question shown above (problem solving skills, time management skills, working in teams and oral communication skills were the four most common responses). The descriptions of personal development revealed that students appreciated the opportunity to develop the skills described above, reflected in statements like "*PBL is a great way to bond with people.*" (Year 1 student, 2015/16) and to develop their independent learning skills:

> *I learnt to never give up when a hard question comes up but to research and ask others for help. I thought it was a great way of learning and finding scientific information out for ourselves.*
>
> *Year 1 student, 2014/15*

C/PBL also gave students an opportunity to apply and communicate scientific concepts learnt in lectures:

> *I feel like the group work was helpful in reinforcing the key ideas of the science learnt in CH1000 (Introductory Inorganic and Physical Chemistry module) and presenting them in a more interesting and relevant way.*
>
> *Year 1 student, 2014/15*

Some student comments highlighted the perceived limitations of the groups which included comments on group size and peer contributions:

> *I think the groups should be smaller as it was difficult to include everyone and some people ended up doing more work than others.*
>
> *Year 1 student, 2014/15*

It was also clear that some students expected C/PBL activities to be aligned entirely to material covered in lectures running at the same time:

> *I think it would be better if only the things that are covered in the lectures are included in PBL.*
>
> *Year 1 student, 2015/16*

Some students appreciated the fact that the C/PBL helped to develop their understanding of the subject beyond the scope of the core lecture module:

> *I liked the fact that some of the problems required you to know certain topics that hadn't yet been covered.*
>
> *Year 1 student, 2015/16*

Evaluation of C/PBL induction activity

The student response to the use of a C/PBL induction activity was extremely positive. Students were very engaged with the process of developing learning resources:

> *Creating something that we can use ourselves that compliments [sic.] the course was a very useful experience.*
>
> *Year 1 student, 2016/17*

Many of the teams planned their evaluations very carefully in order to generate meaningful data from their pilot groups (one group compared responses to their draft resource from students at university and a local school). Teams prepared questionnaires and/or interview questions to facilitate data collection and to ensure that all pilot participants provided a comparable set of responses. This activity helped to welcome students to the learning community as the final resources were showcased to other students and there were opportunities for students to feedback on each other's work. A *Dragon's Den* style pitch was integrated into the activity in 2018 to formalise this process. A wide range of different types of resources was submitted for this activity including card games, apps, booklets, and videos. The coverage of topics in these resources spanned the range of topics covered in a typical Year 1 general chemistry module.

Students were asked about their experience of this induction activity using a questionnaire based on Likert-type responses indicating level of agreement with a series of statements and a small number of open-ended questions. Over 75% of respondents (*n* = 168) in the 2016/17 and 2017/18 academic years agreed that the problem gave them an opportunity to meet new friends, discuss scientific topics with their peers, reinforce their existing subject knowledge, and work on developing a project plan (Williams, 2018). Interestingly, less than 50% of respondents agreed that this activity gave them an opportunity to discuss science with a facilitator. This may reflect the fact that the students were confident that they understood enough chemistry to be able to develop a suitable resource without needing to engage with the facilitator about the topics. This may be a reflection of that fact that one of the entry requirements for the chemistry degree programmes at Leicester is a good performance in A Level chemistry or equivalent. Responses to Likert-type and open ended questions both demonstrated that students felt the development of teamwork skills was the single most useful aspect of this problem (Williams, 2018). This was a positive result for the module team as all subsequent C/PBL based activities in the chemistry degree programme at Leicester are based on teamwork so preparing students for this at a very early stage of their education had obvious advantages. Students also fed back that they felt the problem didn't provide much scope for developing their understanding of new scientific topics (the module team agreed with this as the activity was intentionally designed not to do this) and that there may have been some issues with the timescale of the problem (too much to do in too short a period of time). In response to this feedback, future iterations of the activity incorporated statements to clarify the nature of the problem to help students form realistic expectations of what they would get out of the activity. The problem timescale was also revised to include an optional drop-in help session and the deadline was extended (and moved to a week where there were no other deadlines).

Facilitator reflection on this activity has been very positive and the activity has provided new opportunities for cross-year collaboration. As an example of the last point, a card game based on naming organic molecules developed by Year 1 students in previous years has subsequently been further developed and refined by Year 3 students who have researched the effectiveness of these resources in undergraduate teaching.

Implications and Adaptability: Your Context

Many of the C/PBL resources developed for the chemistry degree programmes at the University of Leicester have been subsequently used in other higher education institutions. Based on discussions with academics at these institutions and my own reflections, a number of recommendations are listed below for someone implementing a C/PBL activity for the first time:

- Think carefully about how C/PBL can work within the context of your programme. What topic areas are most suitable for these approaches to learning? Can existing resources be used or do new resources have to be developed (and, if so, who needs to be involved?). At Leicester, we have found making use of an interdisciplinary team of academic and industrial co-authors to be a highly productive approach.
- Do all necessary preparation in advance of the start of the activity (Table 2). It is helpful to run training sessions for colleagues and/or postgraduate facilitators.
- It can be helpful to run an induction activity before making full use of C/PBL. This allows students to familiarise themselves with the specific characteristics of this approach to learning.
- Consider what additional student development opportunities are offered by the adoption of these approaches. At Leicester, this approach has helped to enhance the development of

workplace skills by chemistry students.

- Think carefully about scheduling and allocation of facilitators to sessions. C/PBL approaches can be very labour intensive if careful consideration isn't given to how best to facilitate sessions.
- Evaluate your implementation of C/PBL. It may be appropriate to ask a third party to help convene discussions with participants about their experience. An adapted version of the questionnaire used by Overton and Hanson (2010) could be used to measure student perceptions of skills development.

Conclusions

The Leicester experience has shown that C/PBL approaches can be effectively integrated into undergraduate chemistry teaching in a way that facilitates student skills development and helps develop student engagement with the subject. Concerns over the efficiency of the approach were overcome through careful planning of the amount of contact time required to support student progress and by making use of trained postgraduates to support the facilitation process. C/PBL approaches have been used at Leicester in a number of very different contexts since the initial implementations but the use of a common problem solving strategy has helped to provide continuity between different C/PBL activities and to support the learning and development journey of students through the programme. In recent years, a number of skills focused C/PBL activities have been introduced in Year 1 of the programme. Some of these C/PBL activities were designed to be implemented widely and are available on the RSC's Learn Chemistry website. These activities have created new opportunities to support student creativity at the early stages of their degree programme and to facilitate student involvement in student-staff partnerships. These approaches have also helped to introduce students to collaborative working practices and independent learning within a scaffolded framework.

Supplementary Information
Supplementary information referred to in this chapter is available at: overtonfestschrift.wordpress.com.

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