vPBL

Williams, Dylan P.

DOI:
10.1021/acs.jchemed.1c01068

JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc Article

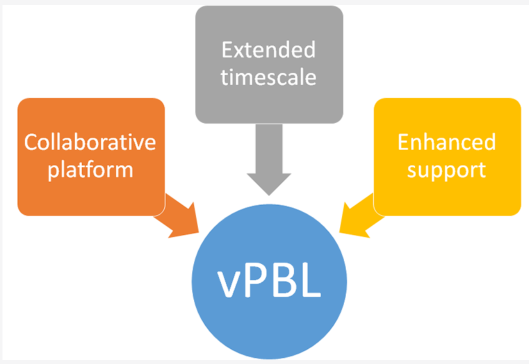
vPBL: Developing a Facilitated Remote Approach to Problem Based Learning

Dylan P. Williams*

Cite This: J. Chem. Educ. 2022, 99, 1642–1650 Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: A classroom based Problem Based Learning (PBL) activity was adapted to run as a remote activity during the COVID-19 pandemic using an approach described as virtual Problem Based Learning (vPBL). vPBL is based on (i) identification of a suitable learning platform that supports collaborative working in a way that mimics the classroom based activity and provides additional flexibility for teams to work together, and (ii) adaptation of the problem structure to provide additional time for students to work together and additional facilitated support where needed. Student performance and self-reported levels of transferrable skills development in the vPBL activity were as good as they were in the PBL version of the same activity. Furthermore, the transition to vPBL appears to have no negative impact on student learning and development. Although there was evidence to suggest students in the vPBL cohort collaborate between sessions to a similar extent as their colleagues who learnt primarily through interactive online lectures, there was evidence of greater use of some collaborative digital learning tools (audio and video chat and desktop and file sharing) in the vPBL cohort.



KEYWORDS: *First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, Collaborative/Cooperative Learning, Inquiry-Based/Discovery Learning*

■ INTRODUCTION

Background

The rapid transition from face to face teaching to either blended or entirely online modes of delivery (referred to as remote learning approaches throughout this paper) necessitated by the COVID-19 pandemic in early 2020 initiated a global conversation about the shape of chemistry education during and after the pandemic.[1−4] In spite of the fact the transition to remote approaches was, in many cases, intended to be a short-term measure, it soon became apparent that the key lessons learnt from this experience could be used to better support and educate chemistry students beyond the pandemic.[5,6]

It can be argued that the transition to remote learning approaches has accelerated the adoption of flipped and blended learning strategies by some educators.[7,8] Examples of remote learning approaches adopted during the pandemic in chemistry education include remote laboratories,[9] laboratory activities that can be safely completed at home,[10] remote lectures,[11,12] student research symposia,[13] and team activities.[14] Different pedagogical models have been adopted to support active learning in remote chemistry activities including use of the Community of Inquiry framework[15,16] and flipped learning approaches.[17,18]

Challenges and Opportunities of Remote Delivery

A variety of challenges were faced by institutions in the adoption of remote learning approaches including the availability of suitable learning technologies and the amount of training required to familiarize students and staff with them.[19] Rap et al. reported the challenges faced by chemistry high school teachers in Israel when making the transition from face-to-face to online teaching. The technological issues associated with this type of transition proved to be among the biggest challenges faced by teachers. Rap et al. emphasized the importance of providing suitable training and support for staff involved in online teaching.[20] It is also worth noting that the transition to remote learning approaches and the associated dependence on technology was shown to exacerbate existing social injustices in Higher Education.[21−23] The latter point is of particular relevance to educators designing remote activities based on teamwork. One potential way to mitigate for this effect is to provide alternative routes such as providing means for students to engage and collaborate remotely.

Petillion et al. reported challenges associated with student engagement, motivation, and time management during periods of remote learning.[24] The authors of this study recommended

Received: October 12, 2021
Revised: March 16, 2022
Published: April 4, 2022

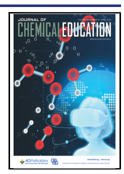


Table 1. Examples of Problem-Based Learning Activities in Chemistry

Title of Activity	Description	Authors[a]
The Future Cities project	This project requires students to work on different aspects of sustainable development.	Overton, T. and Randles, C.
Faster greener chemistry?	A laboratory-based investigation of manganese(III) salen complexes that are used as catalysts in the oxidation of alkenes.	McDonnell, C. and Lanigan, B.
Design your own fireworks show	Students are tasked with the organization of a simulated fireworks display.	MacCready, E. M. and Shermer, G.

[a]All examples are available for download from Royal Society of Chemistry.[34]

that instructors clearly and regularly communicate with students to outline the structure of their course, the nature of the assessed activities, and guidance on how to learn effectively. Another important consideration is the impact of remote teaching on the wellbeing of learners. Currie recommended that educators consider how the sector's response to the pandemic can be used as a platform to improve student and instructor well-being.[25]

The first investigation of the transformation of a classroom active-learning chemistry course to an online activity was reported by Smith et al.[26] This work described the transfer of the established Peer-Led Team Learning (PLTL) pedagogy to an online environment (cPLTL). Students in PLTL and cPLTL groups achieved comparable final exam outcomes, but there were differences in the course grades and levels of student satisfaction with workshops (both higher for PLTL students). The level of effort required to transfer the pedagogy to an online environment was reported to be dependent on the technological approaches used and the level of instructor familiarity with the underlying pedagogy. Although some technological issues were encountered, it was noted that the technology adopted for cPLTL provided some new opportunities for training and assessment (e.g., by using recordings of online workshops).

Problem Based Learning

Problem-Based Learning (PBL) is an active-learning, student-centered approach based on the use of open-ended problems with real-world contexts.[27−29] In common with other student-centered approaches such as Process-Oriented Guided Inquiry Learning (POGIL) and Peer-Led Team Learning (PLTL), the pedagogy of the approach is based on a foundation of social constructivism.[30] Students work in small teams (numbers vary but team sizes tend to be 10 or under) to analyze a scenario, define the nature of the problem, identify agreed goals and outcomes, and to develop solutions to achieve these goals and outcomes. Although PBL shares many of its pedagogical foundations with a range of different approaches, there are significant differences between the types of learning experiences that students encounter when engaging with PBL and other approaches such as Project-Based Learning.[31] When compared to Project-Based Learning, PBL approaches tend to require students to present solutions (e.g., contextualized reports or presentations) to open-ended problems, whereas Project-Based Learning approaches require students to collaborate on projects that can be inspired by open-ended real-world problems. These projects often lead to the development of a tangible product.[32] A PBL community of practice has evolved over recent decades resulting in the creation of a clearinghouse of PBL resources spanning a variety of disciplinary areas,[33] a chemistry specific bank of PBL resources (see Table 1 for examples)[34] and an annual PBL workshop hosted at the University of Delaware.[35] The PBL approach has been used extensively in the Chemistry degree programs delivered by the University of Leicester for over a decade.[36]

Online Approaches to Problem Based Learning

Online approaches to Problem Based Learning had been described before the COVID-19 pandemic (e.g., in distance learning courses[37] or to provide learners with greater flexibility in how they engage with a course[38]), demonstrating the viability of taking an existing classroom based approach and adapting it to meet the needs of remote delivery. Chen described an online PBL model that was based on an existing classroom based implementation in 2016.[38] Evaluation of this approach demonstrated that the online approach to PBL was as effective as the classroom based approach. The author recommended that students receive a clear orientation to the online platform, disruptions are minimized, and instructors provide clear communications to students. Barber and King reported the importance of developing a sense of student belonging to the digital community.[37]

The Chemistry programs at the University of Leicester adopted a variety of remote learning approaches during the pandemic including virtual Problem Based Learning (vPBL), live interactive lecture sessions, and remote laboratory activities. This variety of teaching activities combined with the sudden switch to online teaching provided a unique opportunity to analyze how students use technology to engage with different types of remote learning activities (e.g., by comparing vPBL activities with interactive online lectures).

This paper describes the challenges, outcomes, and reflections on the development of a remote-delivery model for vPBL. The aims of this work were as follows: (i) to develop a model for delivery of an existing Problem Based Learning (PBL) activity using remote learning approaches, (ii) to compare student use of technology in vPBL and interactive lecture approaches used throughout the COVID-19 pandemic, (iii) to measure student perceptions of skills development from the activity, and (iv) to compare student performance in this problem using the vPBL approach with performance in the same activity delivered via a conventional PBL approach.

When developing a vPBL model, it was recognized that efforts had to be made to support student networking and communication and to ensure that students retained ownership of the learning experiences. Jeffery and Bauer reported that the transition to remote teaching approaches had significant impacts on student experiences of laboratory classes.[39] Students reported that the shift to remote learning had a significant impact on their learning in the laboratory. Learning experiences that were normally decision-rich became passive experiences. An additional challenge associated with the shift to online learning was the lack of opportunity for students to study collaboratively. Gemmel et al. have reported that the use of online platforms for collaborative learning can create challenges in developing a sense of community and can result in teams needing more time to complete set problems.[40] In order to minimize these issues in vPBL, a software platform that facilitated effective, synchronous student collaboration and communication was required. The

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650

following section describes the methodology used to develop the vPBL approach.

METHODOLOGY

Background and Participants

The activity chosen for this study was the *Learn on the Move* PBL induction activity,[41] which usually runs as a classroom based activity. Depending on the number of students recruited in a given year, the activity is completed by between 80 and 120 first year Chemistry students. This problem was chosen because it was the first PBL problem due to take place after the shift to remote teaching and because it was students' first experience of PBL and teamwork at university. This problem was originally developed as an induction activity to familiarize students to the PBL approach to learning and to facilitate the formation of social links with other members of their PBL team. The problem is based on the design, development, and evaluation of a learning resource suitable for use with year one chemists.

A full discussion of the activity's content is provided in an earlier publication,[41] but a summary of the key aspects of the problem is presented here:

- Students work in teams of around six to plan and develop a learning resource based on an area of core chemistry (e.g., molecular geometry or covalent and ionic bonding models) required for a General Chemistry course.
- Students are encouraged to adopt evidenced informed approaches when selecting topic area and resource design.
- The target audience for the resource is first year undergraduate chemistry students (in the UK, students typically only study courses from their own disciplinary area).
- Students develop a prototype of their resource and present it to their peers in an elevator pitch presentation (maximum presentation length: 5 min).
- Students use the feedback they get from their peers and facilitators to improve their resource and to evaluate its effectiveness with a small pilot group.
- Students submit the final version of the resource along with a single page report outlining the rationale for the resource design and providing an overview of the outcomes of the pilot evaluation.

Choosing the Learning Platforms

An instructor-led analysis of the activity was conducted in order to identify the key features of the learning experience that would have to be incorporated into the remote version (see Table 2).

Table 2. Key Features That Needed to Be Integrated into the Remote Delivery of *Learn on the Move*

Activity	Description
Collaborative working	Students needed to be able to work collectively during and between contact sessions—they would need the ability to collaborate synchronously and asynchronously.
Facilitation	Staff needed to be able to interact with student teams synchronously—they would need video, audio, and text communication permissions with all student teams.
Communication	Two-way synchronous video and audio communication functionality was important for all participants. Text chat was also likely to be important.
Online submission	The product (learning resource) developed by the students would need to be submitted online, so a suitable platform would need to be provided for this.

The platforms chosen for the requirements (detailed in Table 3) were based on university level guidance (i.e., platforms that were provided and supported by our university). Institutional experts in Digital Learning provided staff training seminars on these specific technologies.

Students were told that they had to use Blackboard Collaborate Ultra for all of the vPBL contact sessions, but that they were free to use other platforms (e.g., instant messaging apps) to facilitate collaboration between contact sessions. The choice of platform was partly informed by institutional constraints (the chosen platforms were licensed to the university and training and technical support was provided for these packages at the institutional level) and partly due to instructor and student familiarity with the platform. Blackboard Collaborate Ultra was a good fit for many of the key features identified by the course educators (see Table 2) and also provided students with some degree of choice in terms of how they engaged with the activity (facilitating the aim of supporting engagement from students with limited access to technology). Alternative collaborative platforms (such as Zoom, Google Classroom, and Microsoft Teams, all of which allow synchronous and asynchronous student collaboration) were considered, but they were not adopted as the institution was unable to support the use of these programs in educational activities. Using this university-licensed and supported platform went some way to addressing previous recommendations for staff training and support. Training sessions were provided by University Learning Technologists to highlight how to make effective use of the platform. This training was followed-up by focused support from Teaching-focused faculty based in the School of Chemistry.[20]

Other courses taught by the School of Chemistry made use of synchronous interactive lectures (referred to as interactive lectures from this point) that were also hosted on Blackboard Collaborate Ultra. The interactive lectures gave students opportunities to contribute by verbally (or textually) asking and answering questions, responding to in-session poll questions, anonymously annotating shared slides, etc. An overview of the key differences of the approaches is shown in Table 4.

Implementation

The classroom based version of *Learn on the Move* is a short, intense activity. The contact sessions take place in the space of a two week window. Resource development and evaluation must be completed no more than 2 weeks after the final contact session. As the transition to remote learning was challenging for many students[21−23] (e.g., because they lost access to a dedicated learning space on campus, they had to find quiet study space at home, and some students had limited access to suitable technology), a new activity structure was created that gave students more time to work on resource development, provided additional flexibility in terms of opportunities for students to remotely collaborate between contact sessions, and introduced additional contact sessions to provide chances for students to discuss their work with a facilitator and to receive feedback (see Figure 1). The key features of this approach were the provision of additional time compared to previous years and the 24/7 availability of a Team Collaborate room, which was set up to allow collaboration using video, audio, text, or screen and file sharing tools.

On the basis of published recommendations, students were provided with regular clear communications to help them plan

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650

Table 3. Remote Learning Platforms Used for the Remote Delivery of *Learn on the Move*

Platform	Description
Blackboard	Learning Management System (LMS) adopted by the University of Leicester. Students and staff were already very familiar with this platform. All vPBL materials were hosted on a course-specific site on Blackboard that also included links to the team Collaborate rooms (see below) and submission points.
Blackboard Collaborate Ultra	Each vPBL team was given its own Collaborate room. The room was left open for the duration of the problem so that students could use the room between contact sessions. Students were given Presenter level access so, in addition to having to the communication tools, they could share desktop screens, share files, use the shared whiteboard, etc., to facilitate teamwork.
Turnitin	The final submission of the developed resource along with its evaluation was managed through Turnitin. All assessment of submitted work was managed in Turnitin. University of Leicester Chemistry students are familiar with this platform from its regular use prior to the pandemic.

Table 4. A Comparison of the Virtual Problem Based Learning (vPBL) and Interactive Lecture Approaches

Type of Activity	Description	Technology Platform Used
Virtual Problem Based Learning (vPBL)	Student-centered. Students work on a set problem in vPBL teams with support from the facilitator.	Blackboard Collaborate Ultra and Turnitin
Interactive lectures	Primarily instructor-led. Mostly didactic approach used with some interactive elements (e.g., use of class polling, live discussion, etc.).	Blackboard Collaborate Ultra

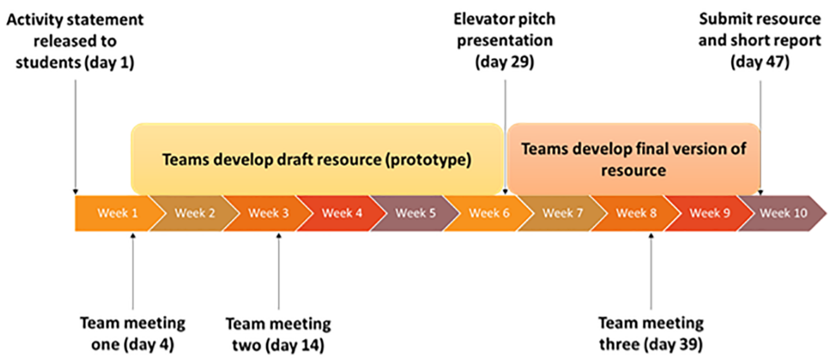


Figure 1. Timeline of the vPBL version of the *Learn on the Move* problem.

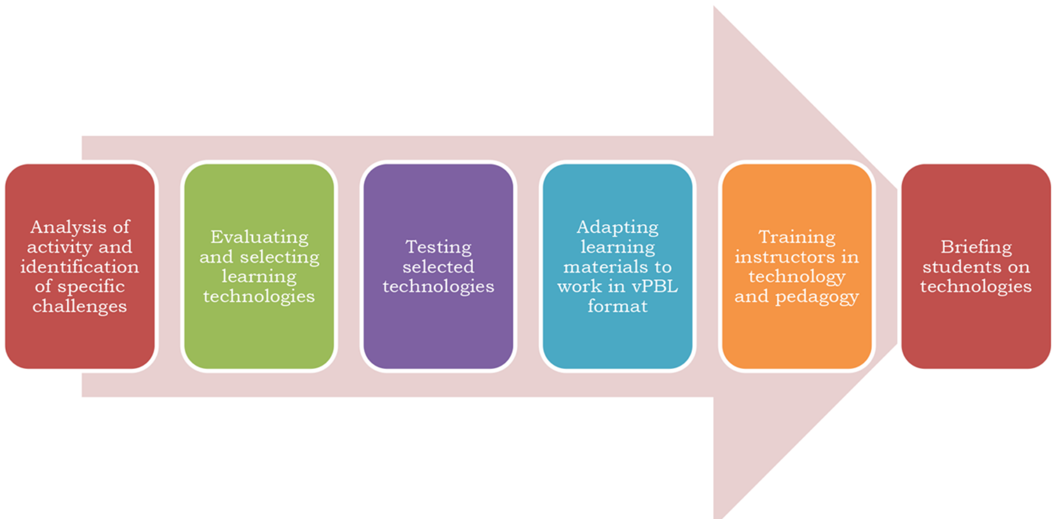


Figure 2. Suggested workflow for adapting a PBL activity to vPBL format.

their time and set their expectations for the term.[37] An instructor-led orientation session was organized for the start of the term on how to use Blackboard Collaborate Ultra and its collaborative tools. A weekly planner was created that provided an overview of the activities and workload throughout the term. A graphical version of this weekly planner was also prepared (see timeline shown in Figure 1). Details of the assessed activities were shared by email throughout the term and all relevant information (e.g., deadlines and assessment criteria) was hosted on the course Blackboard site.

The three team meetings were hosted on Blackboard Collaborate Ultra. Each team meeting had a distinct theme: (1) initial discussion of the problem and planning of solution, (2) reflective discussion of progress made so far and targets for remainder of activity, and (3) focused discussion of how to complete the problem solution. Between team meetings 2 and 3, teams were required to present an elevator pitch presentation of

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650

their prototype learning resource that provided a brief overview of what the resource was, how it worked, and why the particular topic and format had been chosen. The elevator pitch was presented in a live session on Blackboard Collaborate Ultra. This session provided an opportunity to provide feedback to each team. Presentations were not graded, but feedback comments were provided by facilitators and by the members of the other teams as they watched each other's presentations.

Figure 2 presents an overview of a recommended workflow for adapting a PBL problem to vPBL format based on the author's experiences. The first priority is to identify any specific features that are required to facilitate the transition for the PBL activity being considered. Time needs to be spent evaluating and selecting appropriate learning technologies to support student learning. It can be useful to collaborate with learning technologists at this stage to ensure that selected technologies meet the requirements for the problem and that they align with institutional learning technology policies. It is also recommended that instructors allow time for these technologies to be tested (again, with the assistance of a learning technologist). The next stage is to adapt the learning activities to make them suitable for the vPBL format. This may involve changing time scales for activities and preparing support for students. The final preactivity stages are focused on training: training for instructors who will facilitate the vPBL sessions (potentially cohosted by learning technologists and the lead instructor) and briefings for students who will be participating in vPBL activities.

The project and the subsequent evaluation of the activities was conducted in accordance with the University of Leicester's Research Ethics Policy and the project received approval from the School Education Committee. All data were collected via online questionnaires and were fully anonymized with no names or demographic information requested or collected.

Questionnaires were designed to evaluate student use of technology in vPBL and interactive lecture sessions. The first section of the questionnaires asked students to report all of the technological tools that they used at least once during live vPBL and interactive lecture sessions ($n = 30$). All of the tools listed in this first section of the questionnaire were fully supported by the university. The students in both cohorts had the same amount of experience with Blackboard Collaborate Ultra and had received the same type of training and orientation in the use of the technology. Additional insight on student responses was gained from end of year evaluation surveys. (These are standard surveys used at the end of every module to collect feedback on student experience of the module. All student responses are anonymous. See the Supporting Information for details of questions asked.)

■ RESULTS

Use of Technology

An end of activity questionnaire (number of respondents, $n = 46$) was used to evaluate student use of technology during and between vPBL sessions (for reference, the total number of students in this cohort was 82). A separate questionnaire (number of respondents, $n = 30$) was used to collect the analogous data for interactive online lectures from a different cohort within the school who had, at the time the questionnaire was deployed, not encountered vPBL (for reference, the total number of students in this cohort was 111). This allowed a comparison of technology use in the two types of sessions to be made (see Figure 3).

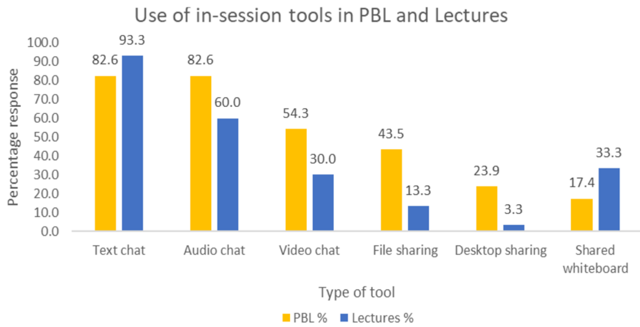


Figure 3. Comparison of responses to the question "Which of the following Blackboard Collaborate Ultra tools did you use at least once during live sessions" for two types of teaching activity: vPBL ($n = 46$) and interactive lectures ($n = 30$).

The most frequent response for both types of learning activity was *Text chat* (tied with *Audio chat* in vPBL sessions). There was evidence of greater use of *Video chat* in vPBL sessions compared to interactive lectures (24.3% greater reported usage, X^2 (1, $N = 76$) = 4.4, $p < 0.05$). This may be a reflection of the student-centered nature of the vPBL sessions (i.e., students spent most of these sessions communicating with the other members of their team rather than with the instructor or the majority of other students). Responses from the same cohort to end of year evaluation surveys revealed some hesitancy to use the video functionality during live lectures possibly because of a lack of certainty about the validity of their contributions (e.g., "*I'm uncomfortable using video in lectures. I might get the answer wrong*"), lack of self-confidence, and low levels of engagement with some interactive lectures. Fear of enforced contribution also appeared to be an issue (e.g., "*Humiliating people into answering questions by calling them out or humiliating them by making fun of them when getting a question wrong*").

There was a statistically significantly greater reported use of *Audio chat* (22.6% greater reported usage, X^2 (1, $N = 76$) = 4.8, $p < 0.05$), *Desktop sharing* (20.6% greater reported usage, X^2 (1, $N = 76$) = 5.8, $p < 0.05$), and *File sharing* (30.2% greater reported usage, X^2 (1, $N = 76$) = 7.6, $p < 0.05$) tools in vPBL sessions compared to interactive lectures. There was no evidence to suggest a significant difference in usage of *Shared whiteboard* (relatively low usage in both session types, X^2 (1, $N = 76$) = 2.6, $p > 0.05$) and *Text chat* (relatively high usage in both session types, X^2 (1, $N = 76$) = 1.8, $p > 0.05$) tools in the two types of sessions. These findings may reflect the nature of the learning activities in the two types of sessions. vPBL sessions are very much student-centered with the focus on collaborative working between students within a small team. Interactive lectures were less student-centered, with the majority of interactions being between instructor and students. Instructors of interactive lecture sessions noted that students often used text chat to respond to instructor-set questions rather than responding using video or audio chat tools.

The second section of the questionnaires focused on technologies used by students to collaborate with each other between contact sessions (see Figure 4). These platforms included those provided by the university (e.g., *Blackboard Collaborate Ultra*, *Microsoft Office Online*, and *Email*) and platforms that students chose to use independently of university provision (i.e., *Instant Messaging* and *Google Docs*). When asked which of these tools were used collaborate between sessions, the most popular response for both types of teaching and learning

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650

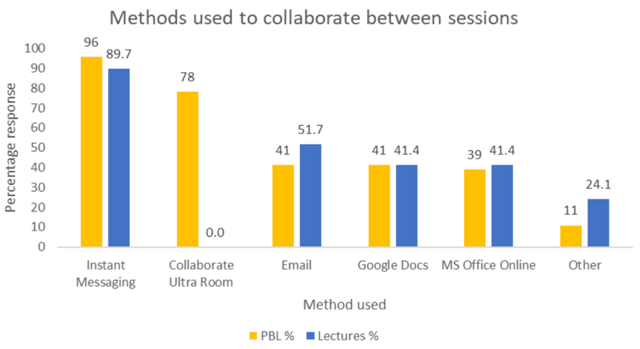


Figure 4. Comparison of responses to the question "Which of the following platforms did you use to study with other students between live sessions" for two types of teaching activity: vPBL (n = 46) and interactive lectures (n = 29; note one questionnaire respondent did not reply to this specific item). Note: Students were not provided with Blackboard Collaborate Ultra rooms for lecture modules.

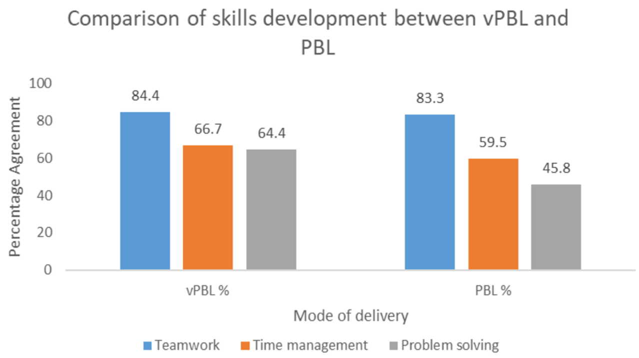


Figure 5. Percentage of respondents who agreed or strongly agreed that PBL and vPBL helped them develop the stated skills or attributes. For vPBL (n = 45; note one questionnaire respondent did not reply to this specific item) and PBL (n = 168).

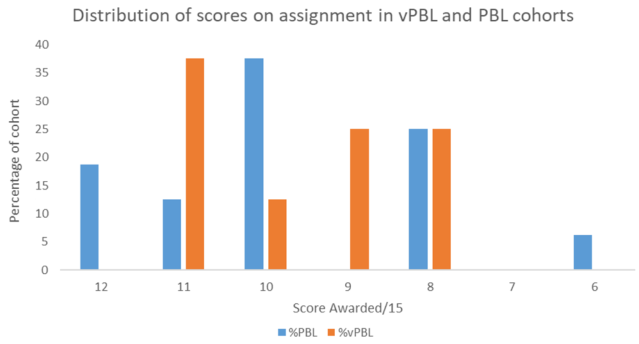


Figure 6. Comparison of the distributions of scores (out of 15) in the *Learn on the Move* activity between PBL (8 teams) and vPBL cohorts (16 teams).

activity was *Instant messaging* with 95.7% of respondents to the vPBL survey and 89.7% of respondents to the interactive lecture survey stating they used this (see Figure 4). 78.3% of respondents to the vPBL survey reported that they made use of the open team Blackboard Collaborate Ultra room to work with other students between sessions (this level of usage exceeded instructor precourse expectations). There was no equivalent of the open Blackboard Collaborate Ultra room for lecture sessions, hence the 0% response. There was similar use of other tools in both types of sessions with no evidence of statistically greater reported use of any tools in one type of session compared to the other (*Instant Messaging:* X^2 $(1, N = 75) = 1.0, p > 0.05$; *Microsoft Office Online:* X^2 $(1, N = 75) = 0.04, p > 0.05$; *Google Docs:* X^2 $(1, N = 75) = 0.0, p > 0.05$; *Email:* X^2 $(1, N = 75) = 0.8, p > 0.05$; and *Other* X^2 $(1, N = 75) = 2.3, p > 0.05$). The other reported approaches used included *Microsoft Office Online* tools, emails, *Google Docs*, and other (non-university-supported) tools (e.g., Zoom and Dropbox). These findings suggest that students in the vPBL and interactive lecture cohorts use these tools to collaborate between sessions to an equal amount. This suggests that collaboration between students may be an important part of the learning experience for both cohorts. It is interesting to note that the data suggest that some students may prefer to create their own approaches to collaborative study in addition to the instructor-provided tools and that instant messaging platforms may be instrumental to these approaches. It has been previously reported that students often favor the use of instant messaging platforms to save time and because of their ease of use.[42]

Skills Development

The next section of the vPBL questionnaire focused on their perceived development of transferrable skills throughout the vPBL process. Students' responses were compared to those collected between 2016 and 2017 when the original version of *Learn of the Move* was run as a standard campus-based PBL activity[43] (see Figure 5). The data suggest that students' perceptions of their skills development (specifically development of time management, problem solving and teamwork) was not adversely affected by the transition to a remote delivery platform.

Student Performance

Figure 6 shows the distribution of grades awarded in 2019/20 (the most recent face to face PBL implementation of the activity) and in 2020/21 (the vPBL implementation of the same activity). The work submitted by both cohorts was assessed by the same academic tutors using the same assessment criteria.

The distributions were compared using an independent samples t test, which verified that the difference between the means of the two cohorts was not statistically significant ($t(22) = 0.11$, $p > 0.05$). Tutors also commented that the quality of the submitted resources and reports was consistent with those submitted in previous years (quality was measured by application of standard marking criteria; see the Supporting Information). It is worth noting that Foo et al. reported that University of Hong Kong Li Ka Shing Faculty of Medicine students who were enrolled in Distance Learning Problem Based Learning tutorials achieved statistically significantly lower scores that students who attended the equivalent tutorials on campus.[44] This difference is not necessarily surprising given the diversity in the types of learning experience that are described by the term PBL. It is perhaps worth stating that this suggests it is challenging to generalize the impact of a transition to remote delivery on student performance in all PBL activities.

It is reasonable to assume that the format changes introduced during the development of the vPBL model have helped to ensure that the transition to remote delivery has resulted in no negative impact on student learning and development for this activity.

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650

DISCUSSION

Instructor Reflections

Although the modification of this classroom based activity to the vPBL format was necessitated by the COVID-19 pandemic, the modified activity may be of broader use beyond the scope of the pandemic. The vPBL approach may be used to scale-up a classroom based PBL activity that had been restricted to small cohort sizes due to limited availability of suitable rooms to run parallel classroom sessions. The vPBL approach may also be used to create new opportunities for multi-institutional or (even international) collaborative PBL activities.

Although the adaptation of a classroom-based PBL activity to a vPBL activity involved a slightly higher instructor workload than simply preparing to run an established classroom-based PBL activity, it did not create insurmountable instructor workload challenges. The most labor intensive part of the process was identifying and testing suitable technological platforms for collaborative work in summer 2020. It is recommended that approximately 1 to 2 weeks is spent doing this. The process can be facilitated by collaborating with learning technologists. Preparing the necessary structures for the vPBL activities (e.g., by setting team rooms up on Blackboard Collaborate Ultra) took no more than two working days. Information issued to students required some modification, but the associated workload was not especially high. It is worth noting that the instructor who led this modification had over a decade of experience of using PBL approaches. It is likely that instructors with limited experience of PBL would require more time to make this type of modification. It is recommended that all instructors involved in development, facilitation, and assessment of vPBL activities receive focused training on relevant aspects both pedagogy and technology.

Online facilitation of the vPBL sessions was effective, although it was more difficult for teams to get the attention of a facilitator when they needed guidance: in a classroom session students can put their hands up, but this was more challenging in the online environment where each team was located in a different breakout room. Each facilitator engaged with four teams in a single 1 h session (allowing the facilitator to spend approximately 15 min with each team). It is recommended that facilitators are not assigned any more than four teams in a single 1 h session as this may make it difficult to spend a meaningful amount of time with each team. The process can effectively be scaled-up for larger student numbers by recruiting additional instructors.

The process described in this article was used as the basis for the subsequent modification of further PBL activities in the chemistry degree at the University of Leicester. These included a second year activity based on the role of chemistry in sustainable energy production. The modification of this activity was successful, but there were some unique problem-specific challenges:

- The second-year activity was scheduled to span both semesters, requiring the timeline to be broken into two separate sections with an extended break for the Christmas vacation in the middle. Teams were supported through the integration of online drop-in help sessions at the start of the second section.
- The activity included a press-conference style presentation that required students to peer-review the other teams' presentations and take a leading role in asking questions when other teams were presenting. In order to prepare students for this activity, a briefing session took place which outlined expectations of audience engagement and etiquette (e.g., turning cameras on when asking questions) and good practice in peer-assessment.

Instructors should be aware that each individual PBL problem is likely to have its own unique challenges that will need to be considered carefully when adapting them to the vPBL approach.

Limitations and Future Directions

This study was based on instructor and student experiences in a single academic year. It is anticipated that further work could be conducted to investigate how transferrable the vPBL approach is beyond a local context (e.g., to other disciplinary areas or institutions). The limited time scale of the study also means the long-term impact of vPBL on student development is currently unknown. It may be useful for this to be investigated in the future.

As described earlier the vPBL approach could potentially be used to facilitate new types of collaborative learning activities that are logistically challenging in a classroom setting. These could include multi-institutional and international learning activities (e.g., where teams are formed from students studying at different universities) as well as interdisciplinary team activities.

CONCLUSIONS AND IMPLICATIONS

This study has demonstrated a proof of concept that can be used to transform a face-to-face PBL activity to run as a remote vPBL activity where needed. The degree of adaptation was modest, but the author recommends that instructors carefully consider the problem time scale and the focus of the support provided to students working on the problem. Students need to receive regular clear communications in order to support their time management. Student collaboration may also be facilitated by providing more time for them to work on the activity and by including additional facilitation sessions (e.g., the *Learn on the Move* problem was extended from 4 weeks to approximately 9 weeks, and the number of facilitation sessions was increased from two to three facilitations).

The choice of virtual platform used to host vPBL activities is likely to be important, and the author recommends instructors identify the key qualities required of the platform before identifying a specific solution. Choosing a platform that (i) digitally mimics the types of interactions that students can have in face-to-face sessions and (ii) is supported by the institution are likely to be important to success. Student use of collaborative tools in different types of online learning sessions appears to differ with evidence of greater reported use of some types of tools in vPBL sessions than interactive lectures (e.g., video and audio chat as well as file and desktop sharing). Due to the challenges students face in collaborating remotely, it is possible that allowing some flexibility in terms of technologies students choose to use may be important. The majority of University of Leicester School of Chemistry students made use of instant messaging platforms to facilitate academic collaboration when working on vPBL and interactive lecture courses. The popularity of instant messaging platforms may be due to their ease of use[42] and student-ownership of these environments (i.e., students can create social media groups and manage membership of them).

Students performed at least as well in the vPBL implementation of *Learn on the Move* as previous cohorts had in the PBL implementations. It is impossible to generalize this conclusion to all PBL activities due to the diverse nature of learning experiences that are classified as being PBL. It is possible that PBL activities that include limited (or no) requirements for practical or hands-on activities may be easier to adapt to the vPBL format.

The findings of this study may facilitate future remote implementations of Problem Based Learning and the development of a hybrid models for Problem Based Learning activities that integrate both classroom and remote elements (e.g., through provision of digital collaborative tools to allow student collaboration between classroom-based contact sessions).

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.1c01068.

Learn on the Move: Adapted Student Handout (PDF) (DOCX)

Learn on the Move: Adapted Instructor Handout (PDF) (DOCX)

Converting to vPBL (PDF) (DOCX)

Survey Questions (PDF) (DOCX)

SET Sheet Information (PDF) (DOCX)

Assessment Criteria (PDF) (DOCX)

■ AUTHOR INFORMATION

Corresponding Author

Dylan P. Williams − *School of Chemistry, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom;* orcid.org/0000-0002-1260-5926; Email: d.williams.12@bham.ac.uk

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.jchemed.1c01068

Notes

The author declares no competing financial interest.

■ ACKNOWLEDGMENTS

The author would like to thank Khalku Karim for contributing to the facilitation of vPBL sessions.

■ REFERENCES

(1) Holme, T. A. Introduction to the J. Chem. Educ. Special Issue on Insights Gained While Teaching Chemistry in the Time of COVID-19. *J. Chem. Educ.* **2020**, *97* (9), 2375−2377.

(2) Sansom, R. L. Pressure from the Pandemic: Pedagogical Dissatisfaction Reveals Faculty Beliefs. *J. Chem. Educ.J. Chem. Educ.* **2020**, *97* (9), 2378−2382.

(3) Rupnow, R. L.; LaDue, N. D.; James, N. M.; Bergan-Roller, H. E. A Perturbed System: How Tenured Faculty Responded to the COVID-19 Shift to Remote Instruction. *J. Chem. Educ.* **2020**, *97* (9), 2397−2407.

(4) Lawrie, G. Chemistry education research and practice in diverse online learning environments: resilience, complexity and opportunity! *Chem. Educ. Res. Pract.* **2021**, *22* (1), 7−11.

(5) Pokhrel, S.; Chhetri, R. A Literature Review on Impact of COVID-19 Pandemic on Teaching and Learning. *High. Educ. Future.* **2021**, *8* (1), 133−141.

(6) Talanquer, V.; Bucat, R.; Tasker, R.; Mahaffy, P. G. Lessons from a Pandemic: Educating for Complexity, Change, Uncertainty, Vulnerability, and Resilience. *J. Chem. Educ.* **2020**, *97* (9), 2696−2700.

(7) Adel, A.; Dayan, J. Towards an intelligent blended system of learning activities model for New Zealand institutions: an investigative approach. *Humanit. Soc. Sci. Commun.* **2021**, *8* (1), 72.

(8) Dietrich, N.; Kentheswaran, K.; Ahmadi, A.; Teychené, J.; Bessière, Y.; Alfenore, S.; Laborie, S.; Bastoul, D.; Loubière, K.; Guigui, C.; Sperandio, M.; Barna, L.; Paul, E.; Cabassud, C.; Liné, A.; Hébrard, G. Attempts, Successes, and Failures of Distance Learning in the Time of COVID-19. *J. Chem. Educ.* **2020**, *97* (9), 2448−2457.

(9) Worrall, A. F.; Bergstrom Mann, P. E.; Young, D.; Wormald, M. R.; Cahill, S. T.; Stewart, M. I. Benefits of Simulations as Remote Exercises During the COVID-19 Pandemic: An Enzyme Kinetics Case Study. *J. Chem. Educ.* **2020**, *97* (9), 2733−2737.

(10) Caruana, D. J.; Salzmann, C. G.; Sella, A. Practical science at home in a pandemic world. *Nat. Chem.* **2020**, *12* (9), 780−783.

(11) Ramachandran, R.; Rodriguez, M. C. Student Perspectives on Remote Learning in a Large Organic Chemistry Lecture Course. *J. Chem. Educ.* **2020**, *97* (9), 2565−2572.

(12) Howitz, W. J.; Guaglianone, G.; King, S. M. Converting an Organic Chemistry Course to an Online Format in Two Weeks: Design, Implementation, and Reflection. *J. Chem. Educ.* **2020**, *97* (9), 2581−2589.

(13) Freeze, J. G.; Martin, J. A.; Fitzgerald, P.; Jakiela, D. J.; Reinhardt, C. R.; Newton, A. S. Orchestrating a Highly Interactive Virtual Student Research Symposium. *J. Chem. Educ.* **2020**, *97* (9), 2773−2778.

(14) Hurst, G. A. Online Group Work with a Large Cohort: Challenges and New Benefits. *J. Chem. Educ.* **2020**, *97* (9), 2706−2710.

(15) Tan, H. R.; Chng, W. H.; Chonardo, C.; Ng, M. T. T.; Fung, F. M. How Chemists Achieve Active Learning Online During the COVID-19 Pandemic: Using the Community of Inquiry (CoI) Framework to Support Remote Teaching. *J. Chem. Educ.* **2020**, *97* (9), 2512−2518.

(16) Garrison, D. R.; Anderson, T.; Archer, W. Critical Inquiry in a Text-Based Environment: Computer Conferencing in Higher Education. *Internet High. Educ.* **1999**, *2* (2), 87−105.

(17) Lo, C.-M.; Han, J.; Wong, E. S. W.; Tang, C.-C. Flexible learning with multicomponent blended learning mode for undergraduate chemistry courses in the pandemic of COVID-19. *Interact. Technol. Smart Educ.* **2021**, *18* (2), 175−188.

(18) Venton, B. J.; Pompano, R. R. Strategies for enhancing remote student engagement through active learning. *Anal. Bioanal. Chem.* **2021**, *413* (6), 1507−1512.

(19) Turnbull, D.; Chugh, R.; Luck, J. Transitioning to E-Learning during the COVID-19 pandemic: How have Higher Education Institutions responded to the challenge? *Educ. Inf. Technol.* **2021**, *26* (5), 6401−6419.

(20) Rap, S.; Feldman-Maggor, Y.; Aviran, E.; Shvarts-Serebro, I.; Easa, E.; Yonai, E.; Waldman, R.; Blonder, R. An Applied Research-Based Approach to Support Chemistry Teachers during the COVID-19 Pandemic. *J. Chem. Educ.* **2020**, *97* (9), 3278−3284.

(21) Devkota, K. R. Inequalities reinforced through online and distance education in the age of COVID-19: The case of higher education in Nepal. *Int. Rev. Educ.* **2021**, *67* (1), 145−165.

(22) Azubuike, O. B.; Adegboye, O.; Quadri, H. Who gets to learn in a pandemic? Exploring the digital divide in remote learning during the COVID-19 pandemic in Nigeria. *Int. J. Educ. Res. Open* **2021**, *2*, 100022.

(23) Karakose, T. Emergency remote teaching due to COVID-19 pandemic and potential risks for socioeconomically disadvantaged students in higher education. *Educ. Process: Int. J.* **2021**, *10* (3), 53−61.

(24) Petillion, R. J.; McNeil, W. S. Student Experiences of Emergency Remote Teaching: Impacts of Instructor Practice on Student Learning, Engagement, and Well-Being. *J. Chem. Educ.* **2020**, *97* (9), 2486−2493.

(25) Currie, H. N. Mindful Well-Being and Learning. *J. Chem. Educ.* **2020**, *97* (9), 2393−2396.

(26) Smith, J.; Wilson, S. B.; Banks, J.; Zhu, L.; Varma-Nelson, P. Replicating Peer-Led Team Learning in cyberspace: Research, opportunities, and challenges. *J. Res. Sci. Teach.* **2014**, *51* (6), 714−740.

(27) Savery, J. R.; Duffy, T. M. Problem Based Learning: An Instructional Model and Its Constructivist Framework. *Educ. Technol.* **1995**, *35* (5), 31−38.

(28) Raine, D.; Symons, S. *PossiBiLities—A Practice Guide to Problem-Based Learning in Physics and Astronomy*; Higher Education Academy, The UK Physical Sciences Centre: York, United Kingdom, 2005.

(29) Engel, C. E. Not Just a Method but a Way of Learning. In *The Challenge of Problem-Based Learning*; Kogan Page: London, United Kingdom, 1997.
(30) Eberlein, T.; Kampmeier, J.; Minderhout, V.; Moog, R. S.; Platt, T.; Varma-Nelson, P.; White, H. B. Pedagogies of engagement in science: A comparison of PBL, POGIL, and PLTL*. *Biochem. Mol. Biol. Educ.* **2008**, *36* (4), 262−273.
(31) Savery, J. R. Overview of Problem-based Learning: Definitions and Distinctions. *Interdisc. J. Probl.-Based Learn.* **2006**, *1* (1), 9−20.
(32) Nagarajan, S.; Overton, T. Promoting Systems Thinking Using Project- and Problem-Based Learning. *J. Chem. Educ.* **2019**, *96* (12), 2901−2909.
(33) Problem Based Learning Clearinghouse. https://www.itue.udel.edu/pbl/problems (accessed January 31, 2022).
(34) Context and problem-based learning. https://edu.rsc.org/resources/collections/context-and-problem-based-learning (accessed 2022-01-31).
(35) PBL Workshop. https://sites.udel.edu/pblworkshop/ (accessed January 31, 2022).
(36) Williams, D. P.; Woodward, J. R.; Symons, S. L.; Davies, D. L. A Tiny Adventure: the introduction of problem based learning in an undergraduate chemistry course. *Chem. Educ. Res. Pract.* **2010**, *11* (1), 33−42.
(37) Barber, W.; King, S. Teacher-Student Perspectives of Invisible Pedagogy: New Directions in Online Problem-Based Learning Environments. *Electron. J. e-Learn.* **2016**, *14* (4), 235−243.
(38) Chen, R. Learner Perspectives of Online Problem-Based Learning and Applications from Cognitive Load Theory. *Psychol. Learn. Teach.* **2016**, *15* (2), 195−203.
(39) Jeffery, K. A.; Bauer, C. F. Students' Responses to Emergency Remote Online Teaching Reveal Critical Factors for All Teaching. *J. Chem. Educ.* **2020**, *97* (9), 2472−2485.
(40) Gemmel, P. M.; Goetz, M. K.; James, N. M.; Jesse, K. A.; Ratliff, B. J. Collaborative Learning in Chemistry: Impact of COVID-19. *J. Chem. Educ.* **2020**, *97* (9), 2899−2904.
(41) Williams, D. P. Learn on the Move: A Problem-Based Induction Activity for New University Chemistry Students. *J. Chem. Educ.* **2017**, *94* (12), 1925−1928.
(42) Lauricella, S.; Kay, R. Exploring the Use of Text and Instant Messaging in Higher Education Classrooms. *Res. Learn. Technol.* **2013**, DOI: 10.3402/rlt.v21i0.19061.
(43) Williams, D. P. Measuring the Effectiveness of an Open Ended Team Based Induction Task. *New Dir. Teach. Phys. Sci.* **2018**, DOI: 10.29311/ndtps.v0i13.2680.
(44) Foo, C.-c.; Cheung, B.; Chu, K.-m. A comparative study regarding distance learning and the conventional face-to-face approach conducted problem-based learning tutorial during the COVID-19 pandemic. *BMC Med. Educ.* **2021**, *21* (1), 141.

https://doi.org/10.1021/acs.jchemed.1c01068
J. Chem. Educ. 2022, 99, 1642−1650