Pre-laboratory online learning resource improves preparedness and performance in pharmaceutical sciences practical classes

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Abstract

In recent years the delivery of practical laboratories classes has been subjected to debate, with regards to pedagogical efficiency. Our aim was to develop a pre-laboratory online learning resource that enhances the preparedness and performance within laboratory classes. A study was conducted using second year Pharmacy students, in which the class was given access to an online learning resource that included visual information, quizzes, safety and theory and this was compared to the laboratory script as a preparative resource for class. Less advice was requested by students and reduced error in practical skills was observed when the online learning resource was used by students, when compared to the laboratory script. Students felt they were able to use the apparatus without requirement of support, and thus were more confident in the laboratory class. This online resource has the potential to overcome the pedagogical limitations associated with traditional delivery of laboratory classes.

Introduction

Practical laboratory classes are regarded an essential aspect of science education in both school and higher education. Laboratory work in higher education science has been shown to enhance practical skills, transferable skills and intellectual stimulation (Carnduff and Reid, 2003). Therefore, the inclusion of laboratories can offer potential benefits such as the application of theory in a meaningful context to facilitate learning; an opportunity to hone practical skills and accrue more generic skills such as time management and problem solving. Laboratory work contributes to a student-directed and inquiry-based learning environment as opposed to teacher-directed learning (Hofstein and Lunetta, 2004).

The effectiveness of traditional delivered laboratory classes

Delivery traditionally involves dissemination of manuals or scripts to students, which has been identified to hinder the potential benefits laboratory classes can offer in terms of skills (Tobin, 1990; Hodson, 1993). A review of first year chemistry practical courses across universities in England and Wales suggested that laboratory scripts were largely instruction driven; which may impede learning (Meester and Maskill, 1995). Students regularly fail to comprehend the purpose of their experiment when utilising a traditional laboratory scripts (Hodson, 1993; Hofstein and Lunetta, 2004). Issues also arise with the format of traditional scripts as it is referred to as a 'recipe' in which students follow the activity step by step; eliminating self-directed learning.

Alongside this, traditional laboratory scripts offer limited reference to procedural skills such as manipulation of apparatus and understanding of different types of laboratory glassware and instruments. This is further complicated by the students' unfamiliarity in a new environment compromising the educational gain from the activity as they are overloaded with information over a short period of time. This can often cause anxiety among students (Huey, 2013; Malakpa*, et al.*, 2013) restricting learning to mere observation. This is further exacerbated with a fixed time allocation for laboratory classes, which is often too short for the activity to be conducted, when allowing for experimental error.

Pre-laboratory tools to aid learning in the laboratory class

Therefore in order to overcome such issues; various pre-laboratory activities have been developed and evaluated, which, for chemistry education have been highlighted in a review by Agustian and Seery (Agustian and Seery, 2017). Most pre-laboratory activities reported are based around three specific rationales that need addressing.

These include the means (i) to introduce theoretical concepts, (ii) to introduce laboratory techniques and (iii) to address affective dimensions.

To introduce theoretical concepts, most of the focus has been on the use of pre-laboratory lectures, quizzes or discussion. The most common formats have utilised online theory presentations (Teo*, et al.*, 2014; Chaytor*, et al.*, 2017), and e-quizzes (Chittleborough*, et al.*, 2007; Jolley*, et al.*, 2016). These approaches have helped students feel more prepared for the laboratory class and raised awareness on concepts that underpinned the experiment.

The most common pre-laboratory activity is to introduce laboratory techniques. These are typically conducted using technique videos, interactive simulations and safety information. This approach has been used in a wide range of science disciplines through the development and application of e-learning tools (Trindade*, et al.*, 2002; Modell*, et al.*, 2004; Dantas and Kemm, 2008; Gautam*, et al.*, 2016). One study which utilised first person demonstrations of laboratory classes (Fung, 2015) provided a realisitic reconstuction of the practical class that students found very useful. Some aspects of the video demonstrations have incorporated safety information of a laboratory class, which has resulted in students showing additional responsibility towards their safety (Alaimo*, et al.*, 2010; Chaytor*, et al.*, 2017).

One of the major benefits of the pre-laboratory activities is to provide an affective experience of the laboratory class to exert confidence and motivation within this specific learning environment. This is specifically linked to the pre-laboratory activities conducted as various studies have indicated that student confidence was increased after viewing pre-laboratory videos (Towns*, et al.*, 2015; Hensiek*, et al.*, 2016; Box*, et al.*, 2017; Seery*, et al.*, 2017).

Pre-laboratory approaches have provided the ability to perform better within the laboratory class and gave students the confidence to work autonomously without the need for constant assistance from laboratory demonstrators or instructors (Johnstone, 1997; Van Merriënboer*, et al.*, 2003; Reid and Shah, 2007; Winberg and Berg, 2007; Agustian and Seery, 2017).

Current research study

To date pre-laboratory learning activities have focused on distinct areas, in which the emphasis and focus has been to tackle one issue of the laboratory class learning environment. However, there are multiple factors that contribute to the ineffective nature of laboratory classes and therefore a single resource that provides the ability to introduce theoretical concepts and laboratory techniques as well as address affective dimensions would be more logical. Therefore, the purpose of our study was to develop a pre-laboratory online learning resource which tackled multiple factors, through the inclusion of different study elements. Therefore, the research questions guiding this study are:

(1) Do students who use the pre-laboratory online learning platform show improved performance in conducting the activities in the laboratory class?
(2) Are there differences in the usefulness of the different activities developed for the pre-laboratory online learning platform?
(3) Do students feel more confident in conducting the activities within the laboratory class independently when using the pre-laboratory online learning platform?
(4) Do students show greater awareness of laboratory safety by using the pre-laboratory online learning platform?

Methods

Study design

The study design was approved by the University of Brighton Ethics committee. The study was conducted by developing a pre-laboratory online learning resource for the 2nd year pharmaceutical sciences module, which is a compulsory module undertaken by the second year Pharmacy cohort. Within this module students undertake 5 laboratory sessions in which 2 sessions were part of this study. The activities conducted in the laboratory classes that were utilised in this study had no bearing on the overall grades of the students. **Supplementary Table 1** shows that there were no demographic differences between the two groups with respect to gender ratios, age and grade point average from their first year of studies. Students were introduced to basic experimental techniques and analytical chemistry from first year of study.

Figure 1 shows a flow chart showing the study design as part of the research project. As part of the cross-over trial, one group of students gained access to the pre-laboratory online learning resource for one laboratory session and the other group was given access to the traditional script and underlying theory (run in the first semester); and vice versa for the second laboratory session (run in the second semester). Prior to commencing the research study, all the students were informed about the study and to raise any concerns, of which none were received. Students were also informed not to share this content with students in the opposing group. Students in both groups were encouraged to continue to use any additional pre-laboratory activities they may have utilised prior to this study. Students were given access to the online learning resource two weeks prior to the date of the laboratory class via the virtual learning environment (VLE) Blackboard®. An email was sent with instructions on how to use and navigate the online learning resource. Within laboratory classes, students were asked to work in teams of 4 from the same group (either A or B) to complete the activities and were given a total of 3 hours to complete the laboratory class.

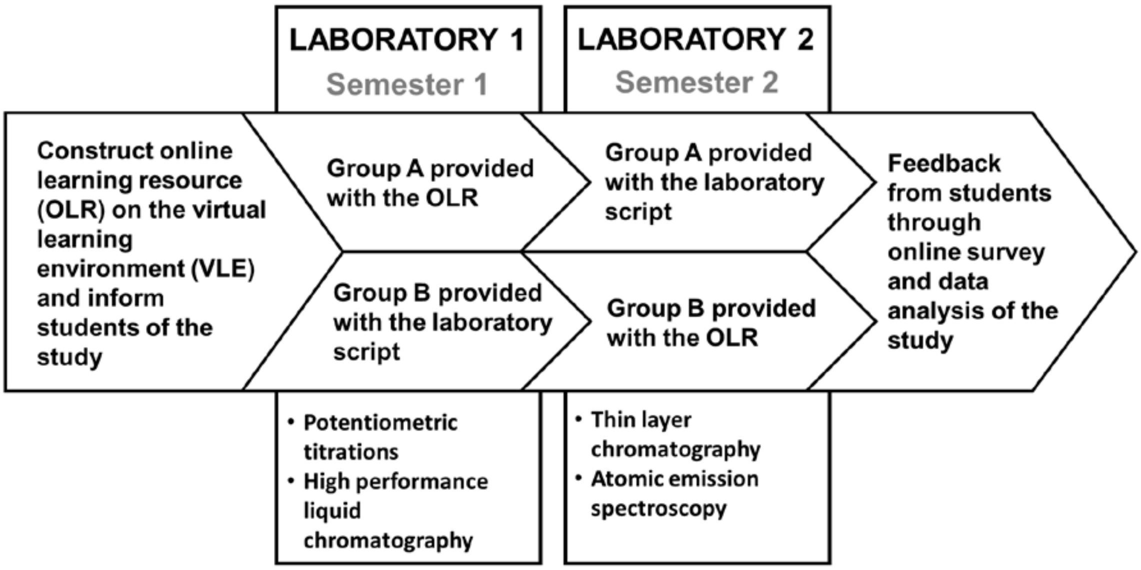

Figure 1. Study design utilised for the evaluation of the online learning resource as a preparative tool for laboratory classes

Development and evaluation of the online pre-laboratory online learning resource

Details on the process taken for the construction of the online learning resource can be found in **Supplementary information**. The pre-laboratory online learning resource was fragmented into various sections, including the experimental demonstrations (which contained videos with >10 minutes duration and visual cues), background theory, key safety information, a quiz, and the traditional laboratory script (**Supplementary Figures 1 - 5**).

To evaluate the success of the new online learning resource as a preparative tool, we utilised multiple metric and observational assessments which are detailed in **Supplementary information**. Briefly, we utilised online tracking metrics on the VLE Blackboard® to assess engagement. Within the laboratory, demonstrators/technicians (who were blinded to which resource the students were given) monitored the number of incidents of poor experimental practice. Finally, to evaluate the perception of students on the usefulness of the online resource, an online survey was provided.

Results

The data shown are the combined results from laboratory 1 and 2, where no differences in the outcomes between each laboratory were observed.

Engagement with the online learning resource

Figure 2 shows the degree of engagement students had with the pre-laboratory online learning resource. Only 27 of 137 students did not engage with the resource. The average time of engagement was 63 ± 90 minutes (n=137, **Supplementary Figure 6A**). **Supplementary Figure 6B** shows that most of the student's access the online resource on at least one day prior to the laboratory classes.

Engagement of individual components of the pre-laboratory online learning resource was evaluated (**Figure 2A & B**). Students spent most of time reviewing the demonstrations (29 ± 24 mins), followed by the theory (17 ± 32 mins), quiz (13 ± 27 mins) and safety information (3 ± 4 mins; p<0.001, n = 137). Students who engaged with one aspect of the online learning package tended to engage with all other elements. On average students viewed the demonstrations significantly more times than the theory, safety information and quiz (p<0.001, n=137). Students viewed the safety information significantly more often than the theory (p<0.01, n=137).

From our questionnaire analysis, students found the online learning resource easy to use. All Likert scores were 3 and above suggestive that every aspect of the pre-laboratory online learning resource was useful to the students (**Figure 2C**). However, the demonstrations were perceived to be significantly more useful than the theory and quiz (p<0.001, n=68). The safety information was also considered to be more useful than the theory (p<0.01) and the quiz (p<0.001).

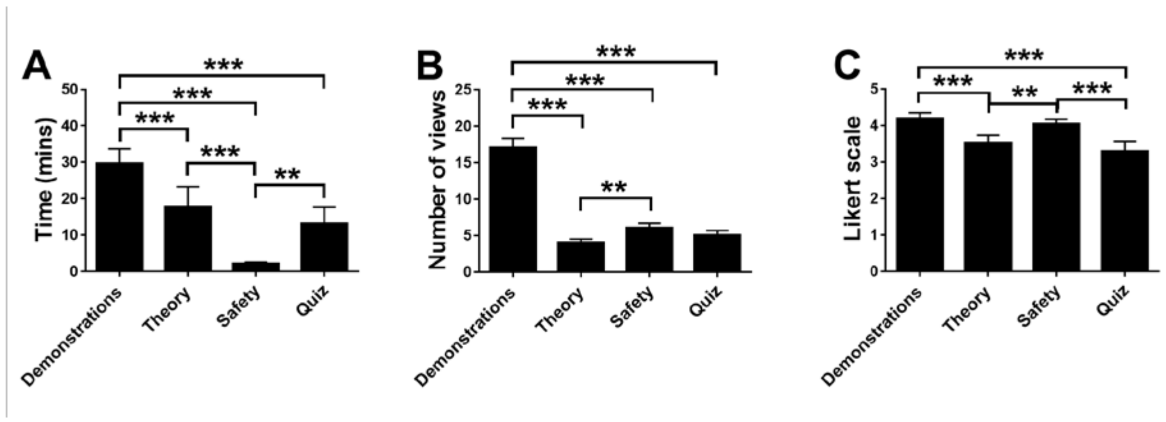

Figure 2. Engagement with the various elements of the pre-laboratory online learning resource, where (A) shows the time students on average spend on the four key elements of the resource, (B) shows the average number of views per student for each element of the resource and (C) shows the student perception on which elements of the online learning package were useful, where 1 indicates not useful and 5 indicates very useful on the Likert scale. Data shown as mean ± st.dev., where **p<0.01 and ***p<0.001.

Evaluation of student performance in the laboratory

Figure 3 shows that there was a significant decrease in the number of incidents when the pre-laboratory online learning resource was utilised (p<0.01, Chi-squared test). The incidents of technique error when the pre-laboratory online resource was utilised was three times less than when the laboratory script was. The incidents of technical advice that were required when the pre-laboratory online resource was utilised was two times less than when using the laboratory script. The number of incidents that guidance was given on how to conduct the calculations of the data generated was much closer between those students utilising the laboratory script or online learning resource, however this aspect was not a feature of the online learning resource.

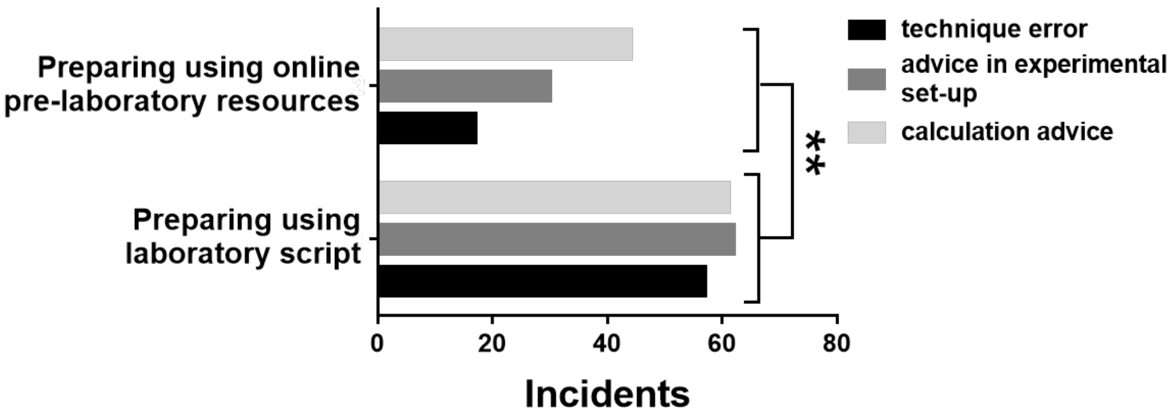

Figure 3. Incidents of technique error observed, advice given on experimental set-up and advice on conducting calculations when interpreting the data generated from the laboratory class. Chi squared test where **p<0.01.

The time taken to prepare 5 solutions to conduct a calibration response by HPLC (laboratory 1) and AES (laboratory 2) was monitored. The average time to prepare all five volumetric solutions was 28.5 ± 7.2 minutes when using the pre-laboratory online resource, which was significantly less than when using the laboratory script, which took on average 57.6 ± 12.9 minutes (p<0.001, n=20). When using the pre-laboratory online learning resource, there was a significant reduction in the number of inaccurate menisci when compared to using the laboratory script (p<0.001, **Figure 4A**). There was a significant improvement in the precision of the highest standard solution analysed by both HPLC and AES when using the pre-laboratory online learning resource as preparative material (p<0.001, F-test, **Figure 4B & C**).

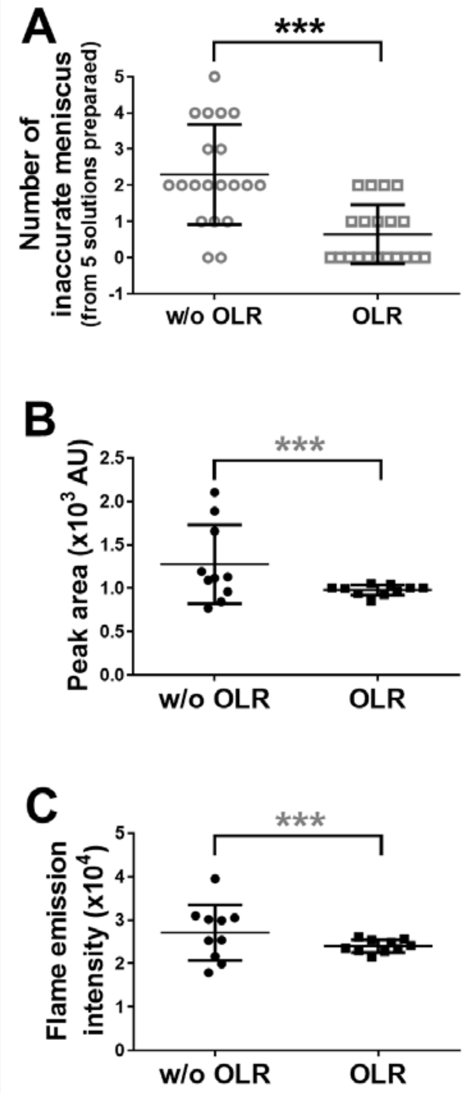

Figure 4. Preparation of stock solutions utilised for the generation of calibration curves by either analysis by HPLC or AES in the presence and absence of the pre-laboratory online learning resource (OLR). (A) photograph of volumetric solutions prepared in a class where the laboratory script was used for preparation, (B) the number of inaccurate menisci, (C) responses of the highest standard solution by HPLC and (D) AES. Data shown as mean ± 95% C.I. where ***p<0.001.

Perception of the benefits to laboratory performance and confidence

A survey was conducted to ascertain student perceptions of the online learning resource in comparison to the laboratory script as a preparative tool. The survey was available to complete until the start of the assessment period, where 85 out of 137 (62

%) students completed the survey. **Figure 5** shows the response from the survey presented as a Likert score. There was a significant increase in the students feeling more able to complete the laboratory class activities in time using the pre-laboratory online learning resource when compared to the laboratory script (p<0.001). Students also felt they gained a greater understanding on how to use the apparatus in the laboratory class (p<0.001). Students also felt more confident in attempting to conduct activities in the laboratory class without need of support from technical and demonstrative staff when they had used the online learning resource as a preparative tool for classes (p<0.001). Finally, the pre-laboratory online learning resource provided important awareness of the potential hazards and risks within the class when compared to the laboratory script (p<0.001).

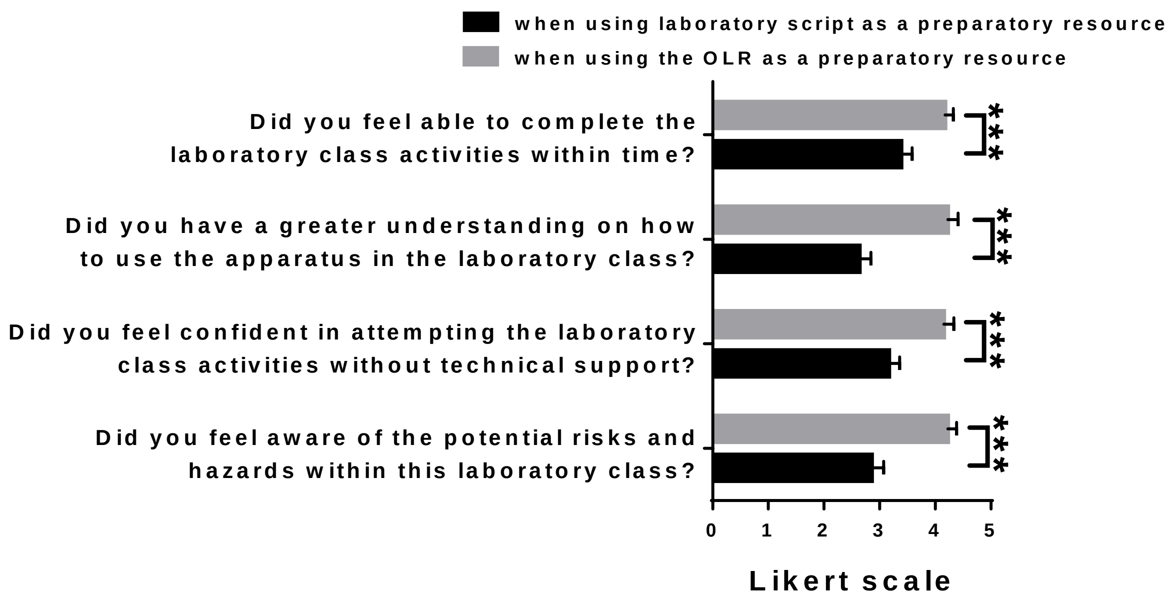

Figure 5. Survey responses exploring student perception of the benefits of the pre-laboratory online learning resource (OLR) as a preparative tool for laboratory classes when compared to using the laboratory script. Reponses presented as Likert scale, where 1 is disagree and 5 is strongly agree. Data shown as mean ± st.dev., n=85, where ***p<0.001.

Discussion

Our findings indicate that providing a pre-laboratory online learning resource which covers multiple elements of the learning environment of a laboratory class can be a beneficial tool, to support student preparation, to conduct the laboratory class with greater confidence and enhanced performance. Our findings show that students engaged with the online learning resource and found its content useful.

With all online learning resources, engagement is a key factor and therefore we reviewed the analytics behind the developed resource. We received 80 % engagement rate for the use of the online resource. The extracted data suggests that students responded and interacted with pedagogical activities differently; as the number of times students accessed different elements of the online resource and the duration they used the resource varied across the cohort. However, it is hard to fully understand the extent of learning engagement conducted using viewing time and duration. Certain aspects of the pre-laboratory online resource as shown in Figure 3 were viewed for longer, such as the visual demonstrations and information on laboratory safety. This may be due to the time taken to conduct these specific activities or that these resources were more complicated or interesting. Although the quiz and background theory was viewed to a lesser extent, other studies have shown these resources have improved preparation in laboratory classes (Chittleborough*, et al.*, 2007; Jolley*, et al.*, 2016; Agustian and Seery, 2017). Most importantly students spend time on evaluating health and safety, which like other studies raises awareness of safety in the laboratory (Alaimo*, et al.*, 2010; Chaytor*, et al.*, 2017). Overall the students found all aspects of the online learning resource useful and therefore the entire package can provide benefits when compared to a single entity.

The visual demonstrations provided in the pre-laboratory online learning resource (see Supplementary Figure 1) was presented slightly different to other approaches utilised (Fung, 2015; Gautam*, et al.*, 2016), as the practical activities conducted were broken down into visual cues and videos that demonstrated key techniques and provided guidance on experimental procedures, highlighting incorrect practices. Most students feel information is transmitted more effectively by encompassing visual cues and short activities which require short amounts of time to engage with (Patterson, 2011). This was emphasised by the fact that students found themselves more aware of the safety concerns within the laboratory class (Figure 6) when using the pre-laboratory online learning resource. Safety information is usually a section of written information provided in the laboratory script rather than pictures as in the online learning resource (Supplementary Figure 3).

The pre-laboratory online learning resource allows for a personalised learning experience in which there is increased flexibility, allowing students to learn and prepare within their own time frame, pace and learning environment; theoretically providing a reduction in cognitive load. This has been identified by various educational research studies as a strength of online learning environments and supports this work (Albrecht, 2006; Winberg and Berg, 2007; Seery and Donnelly, 2012). However, it was not possible to determine if other e-learning approaches would be as effective, or if only some components of our online learning resource would be as effective as the entire package.

The effectiveness of the preparative approach was evaluated in the laboratory class, as the performance of the students to conduct the activities were observed and monitored. There was two times more incidents for information on how to set-up apparatus in the practical class and three times more incidents on poor experimental practice, when the laboratory script was used in comparison to the online learning resource. This was also observed in another study in which the number of students asking questions during the experimental was significantly reduced after implementing pre-laboratory activities (Johnstone, 1997; Reid and Shah, 2007; Winberg and Berg, 2007). No difference in the number of times advice was given on how to conduct the calculations to interpret the experimental data was observed. This is a key observation as this element was not a feature of the preparative material in either the online resource or the laboratory script and served as a suitable control between both groups.

Due to the lack of errors or need for advice given within the laboratory class, students were able to complete the practical much quicker than those who prepared for the class using the laboratory script and therefore the additional time gained could be utilised to further enhance the learning experience by explaining aspects of the laboratory class or reflecting on the data generated. Students were also able to improve on their accuracy and precision in preparing standard chemical solutions as shown in Figure 5. This may be due to the nature of the virtual cues provided which leave the students the opportunity to reflect on appropriate practice in the laboratory setting (Trindade*, et al.*, 2002).

If this online learning resource was implemented across undergraduate teaching; time spent carrying out procedural aspects of the laboratory would decrease, allowing the instructor to allocate the remaining time for reflection on practical class. This would induce a better learning environment in which a discussion could be held, providing an opportunity to foster comprehension of the scientific principles. Self-reflection in many forms such as video feedback, instructor feedback and e-resources has been found to increase science process skills in general chemistry labs (Taylor*, et al.*, 2009) and development of scientific abilities in physics labs (Etkina*, et al.*, 2010).

The online learning resource through student feedback by questionnaire, showed that they feel more able to complete the class through understanding how to use the apparatus and therefore felt more confident to conduct the laboratory class without additional support. These findings clearly indicate the positive impact this learning resource can have on preparedness and performance, and importantly provides students with confidence to be more active in the classroom without the anxiety of conducting an activity.

Conclusion

We have developed a pre-laboratory online learning resource that provides varying learning environments. This resource has positively impacted the students' educational experience in the laboratory class through enhanced preparedness and performance. Students highly engaged with the online learning resource finding the online demonstrations of experimental activities and safety information to be of significant value. Our online learning resources enhanced student performance and confidence, which was evidenced by reduced error in experimental practice and enhanced accuracy and precision of chemical solutions prepared. Due to the enhanced experimental practice in the laboratory class, students were able to complete the activities much faster time providing scope to enrich the educational activity.

Author contributions

CS generated the online learning resource through support of MC and MJI supported in survey design. CR conducted cohort analysis. ES, AF, PK, AQ, SM, JS and CSm conducted observational analysis in laboratory classes. CS, MJI and BAP conducted the data analysis. CB and BAP designed the study.

Biography

Charlotte Sarmouk is a undergraduate chemistry student within the School of Pharmacy and Biomolecular Sciences at the University of Brighton

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