Pharmacognosy Communications
Volume 4 | Issue 1 | Jan–Mar 2014

www.phcogcommn.org

Invited Article

Implementation of a Virtual Laboratory Practical Class (VLPC) module in pharmacology education

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Abstract: The Virtual Laboratory Practical Class (VLPC) computer program is a resource aimed at improving practical laboratory performance and understanding in a second-year pharmacology student cohort. In our evaluation of the program, half of the 233 students were provided access to the VLPC before their laboratory session and half after the completion of their experiment. Surveys were conducted to gauge student perception and understanding of the laboratory experiment. In addition, data measuring student completion times for the laboratory task were collected. Students who used the VLPC before the class reported an increase in their confidence in successfully completing the live practical experiment. They also showed a significant decrease in the mean completion time for the real laboratory session. No effect of the VLPC on assignment scores was observed, however this is likely due to the content of the program, which comprised only a very minor portion of these assessable laboratory reports. While some operational issues affected students' use and engagement in the early stages of the project, students reported benefits to their practical skills and understanding, and perceived the VLPC as a realistic and useful depiction of the laboratory environment.

KEYWORDS: computer simulations; virtual reality; human-computer interface; interactive learning environments

INTRODUCTION

There is substantial literature describing virtual, three-dimensional worlds and laboratories in higher education curricula (Bainbridge, 2007; Jarmon et al., 2009; Dalgarno et al., 2011). Pharmacology is one discipline that has been included in these computer-based learning approaches (Hughes, 2002; Efferth, 2011).

BIOM2402 (Principles of Pharmacology) is a 2nd-year science course at the University of Queensland where practical sessions are complemented by a computer-assisted laboratory (CAL) exercise that is completed before the laboratory classes. However, this computer program (Stevens and Sewell, 1993) is relatively simplistic by contemporary standards and does not attempt to represent the real-life laboratory. Time constraints on practical sessions result in many students being unable to complete their experiments and analysis within the 3-hour time frame, a problem noted elsewhere (Feisel and Rosa, 2005). Such restraints can also reduce meaningful learning and lead to an unrealistic portrayal of the scientific experimental process (Johnstone and Al-Shuaili, 2001). In the absence of context, it has been argued that traditional "recipe-based" practical classes limit student understanding of how to do laboratory experiments or of what the outcomes of the laboratory classes actually mean (McGarvey, 2004; McDonnell et al., 2007). As a result, negative impacts are being observed on students' abilities to understand and complete laboratory practical classes. These factors are compounded by the increasing student enrolment numbers in many courses which leads to reduced staff-to-student ratios.

In the present study, we investigated whether student laboratory performance and confidence in carrying out experimental procedures could be enhanced by engaging in a virtual laboratory that closely replicates the real-life laboratory. The Virtual Laboratory Practical Class (VLPC) is a simulated environment that can provide students with a "pre-lab" experience (Hodge et al., 2001). Students can "perform" experiments with virtual laboratory equipment to foster their practical skills, a feature lacking in earlier

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DOI: 10.5530/pc.2014.1.2

virtual laboratory designs (Bell, 2004; Ma and Nickerson, 2006). The program was not used as an alternative to the real laboratory task, but was integrated into the laboratory requirement, building on the observation that virtual laboratories can be an enhancement to student practical learning (Raineri, 2001; Engum et al., 2003; Bhargava et al., 2006).

Student use of the VLPC required only a computer and an internet connection. The use of web browsers in virtual laboratories, without any need to install specialized software, affords convenience and accessibility for the wider student population (Gillet et al., 2001; Harris et al., 2001; Ogot et al., 2003). In the present study, we designed the VLPC to improve student laboratory skills and confidence in this first iteration of the module. Whilst student laboratory assignment scores were also collected and analysed as part of this study, the assignment constituted only a small component that was relevant to the content of the program. Instead, our primary focus was on the analysis of in-class laboratory performances, online student activity data from the VLPC internet server, and student perception data that related to various aspects of the virtual laboratory program.

PROJECT OVERVIEW

Design

The VLPC was developed as a web-based application supported by Firefox, Safari and Chrome internet browsers (Chen et al., in press). Students were able to access the program from any location using their student login and password.

The VLPC required students to (1) prepare a number of different drug samples over a range of concentrations, (2) measure the effects of these drugs on biological tissues using an organ bath apparatus and (3) plot and analyze the acquired data and then submit their results and comments online. The program simulates tasks and objectives that are relevant to the real-life laboratory practical. One of the "bench views" in the VLPC is shown in Fig. 1. The VLPC also featured access to high-definition videos (Fig. 2) within the module that included instructions on how to use the VLPC and demonstrations of various laboratory experiments.

Participants

All student participants were enrolled in a single biomedical course (BIOM2402) that introduces students to basic and intermediate pharmacology. The total student cohort of 233 students consisted primarily of Bachelor of Medicine (40%), Bachelor of Science (30%) and Bachelor of Biomedical Science (15%) students. The remaining students were enrolled in dual degree programs, such as Bachelor of Science/Engineering.

The students were divided into 2 major cohorts consisting of 3 individual practical (P) groups that performed their real-life experiments on different dates (each individual P group contained approximately 40 students). The first cohort (Groups P1–P3), consisting of 123 students, completed their laboratory classes and then submitted the assessed laboratory report. Later in the semester, the VLPC was then released online and available to these groups as part of their course revision and preparation for assessment. The second cohort (Groups P4–P6) consisted of 110 students. These students completed the VLPC online within the week before their laboratory class; they then completed the scheduled laboratory work and submitted their laboratory report. For the purpose of our study, the student groups who used the pre-laboratory virtual module before performing the live experiment have been designated "VLPC-prior", while the groups without access to the VLPC before the real laboratory are labeled "VLPC-post".

Thus, for clarification, the course contained 2 major *cohorts* (VLPC-prior and VLPC-post), each containing 3 P *groups* (P1–P3, and P4–P6). Also, within each P group, students worked in *teams* of 2–3 individual students.

PROCEDURE

The types of data acquired during the evaluation project were perception (surveys, online feedback and a focus group) and performance (laboratory completion times, assessment scores and online data). The source of all data was the BIOM2402 undergraduate student cohort.

Pre-laboratory surveys

An optional survey of 10 questions was distributed to all students at the beginning of their laboratory session. The objective was to examine student perception of experience and confidence in laboratory tasks before undertaking the experiment. Questions were designed to address students' perceptions of ability to perform calculations, hands-on laboratory skills, and to analyse and interpret the data collected during class. Students were asked to provide a score ranging from 1 (not confident at all) to 7 (very confident) for the following statements:

1. Choosing and applying an appropriate formula to calculate a drug dilution.
2. Using two-stop pipettors, with pipette tips, to acquire accurate volumes of samples.
3. Using two-stop pipettors, with pipette tips, to deliver drug dilutions to tubes and equipment.
4. Calculating volumes and concentrations for a drug to be applied to an organ bath.

Figure 1. A depiction of a section of the laboratory workbench space areas included in the VLPC. Not shown is an 'Analysis and Feedback' page where students can plot data and compare it to model results.

5. Physically preparing serial dilutions of a drug.
6. Using the correct procedure for applying drugs to an organ bath.
7. Using correct procedure in performing wash steps on an organ bath.
8. Accurately transferring raw data from an organ bath procedure into graph format.
9. Correctly explaining how to use the lab equipment and apparatus in this experiment.
10. Correctly explaining the purpose of the experiment to another student.

Time of experiment completion

Following a brief introduction, the times at which each laboratory class began were recorded for each group. Students were then requested to initial a sign-off sheet upon the completion of their experimental work for the day, and recorded their time of completion.

VLPC online-acquired data

Data on the use of VLPC online were obtained from activity and action logs recorded by the program. The simplest of these logged the total session time and the idle time (the sum of time periods when the mouse or keyboard were inactive for >60 sec). Subtraction of the idle time from the session time yielded the "active time" to gauge the durations of active student VLPC engagement. In addition, an action log file recorded all 'action events' by a student during a VLPC session and the duration of activity associated with specific tasks (e.g. changing pipette volumes, adding solution to a sample tube, moving an object on screen, opening and closing of video resources). However, this additional analysis of the action log functionality, and the learning analytics and insight that this can provide to the use and operation of the VLPC resource, is the topic of a separate study currently underway by our group. Clickable comment boxes were available on each page to allow students to provide written feedback on the program.

Figure 2. An example of one of the video pop-up components within the VLPC program.

Post-laboratory surveys

A second survey was conducted during the final week of semester to obtain perception data from all students concerning the use of the VLPC computer program. Survey Monkey® was used to collect responses online from participating students. In an attempt to eliminate position bias, the questions were randomized so that they were not grouped by the nature of the questions. Participants were permitted to skip questions they did not wish to answer. The types of questions were later grouped by theme, on the basis of VLPC engagement, laboratory understanding and skills, confidence, and realism of the module.

Student assignment scores

An assessment component within the course is a laboratory report (assignment) that is weighted at 25% of the students' final grades. It is based on laboratory sessions during which students perform various pharmacology experiments. Each student laboratory report was marked with a maximum possible score of 42. Although only a small section of the assignment was relevant to the content of the VLPC, the assignment scores were collected and the average scores for the VLPC-post and VLPC-prior cohorts were compared.

Statistical analysis

All data for the VLPC-prior students who did not use the VLPC were excluded from statistical analysis, since they did not use the module being tested. Pre-laboratory survey scores were subjected to unpaired Students' *t*-tests for each individual question (two-tailed; confidence intervals of > 95%) when comparing the VLPC-prior and VLPC-post students. This same test was applied for the analysis of the laboratory completion times, assignment scores and server active times for the two student cohorts. Analysis of the assignment scores and server active times for the 6 student P groups was accomplished by one-way ANOVA with a post-hoc Tukey's multiple comparison test. GraphPad Prism (version 5.04 for Windows) was utilised for each of the preceding tests, where the independent variable was the use of the VLPC while the dependant variable was the observed result of the use of the program. A Pearson product-moment correlation coefficient was calculated (SPSS v.16, Chicago, USA) to determine any dependence between the two variables of student VLPC active times and assignment scores.

Means and standard errors of the means were reported for the server active times of participating students. Post-laboratory surveys were collected from VLPC-prior students only, and presented as percentages of respondents who had chosen from the 'Agree', 'Neutral' or 'Disagree' categories within the survey.

ETHICAL ISSUES

Since the earlier practical groups (P1–P3) did not have access to the VLPC module before their laboratory session, it is possible that these groups may be disadvantaged in their laboratory proficiency and comprehension. Therefore, all students were granted access to the VLPC on the date it was released. Although the order of VLPC access and laboratory work was different for the two groups, both were able to and did use the resource prior to the final examination at the end of semester.

Another ethical concern was the potential effect, if any, of the module on student assignment scores. While the VLPC was designed in its first version to have an impact on student confidence and skills in the laboratory classroom, we did not expect any effect on the assignment scores since the content of the VLPC comprised only a small portion of the summative assessable report. Nonetheless, the ethics application for this project conveyed this information, with the understanding that the student group scores would be moderated accordingly should any disadvantage be observed for any group. Indeed, an ethical clearance application covering all aspects of the study, which included the experimental design and analysis of the results, was approved by the Behavioural and Social Sciences Ethical Review Committee at The University of Queensland (Brisbane, Australia). Also included were copies of student and tutor consent forms, as well as descriptions of the procedures employed to inform students of the nature and purpose of the individual evaluation protocols prior to their commencement.

RESULTS

Student participation

Only 14 of the 233 students did not complete the VLPC module during the semester, corresponding to a 94% participation level. Of the 110 students in the VLPC-prior cohort, 91 (83%) of these students did so prior to the commencement of their practical session, while 12 submitted late and 7 did not submit at any time throughout the semester. VLPC-post students could only submit the module after their laboratory session (with an extended due date), since the VLPC was unavailable before their scheduled practicals. All data from VLPC-prior students who did not participate in the VLPC were excluded from any further analysis.

Pre-laboratory surveys

Immediately prior to the laboratory class, surveys were conducted in order to measure student confidence in their skills, use of calculations, and interpretation and analysis of data. The effects of the VLPC on these scores were examined by graphing the means and standard errors for scores from both VLPC-prior (n = 82) and VLPC-post (n = 90) cohorts and applying statistical analysis (Fig. 3). Very significant increases ($p < 0.01$) in average confidence scores for questions 5, 6, 7 and 9 were observed in VLPC-prior students compared with VLPC-post students. Although increases in the mean scores for the remaining questions were observed in VLPC-prior students, these changes were not statistically significant.

Time of experiment completion

The average experiment completion times for each individual practical group were determined. Our initial statistical analyses (data not shown) revealed that there was a significant reduction in the mean laboratory times in two of the VLPC-prior groups (P4 and P6) compared to the

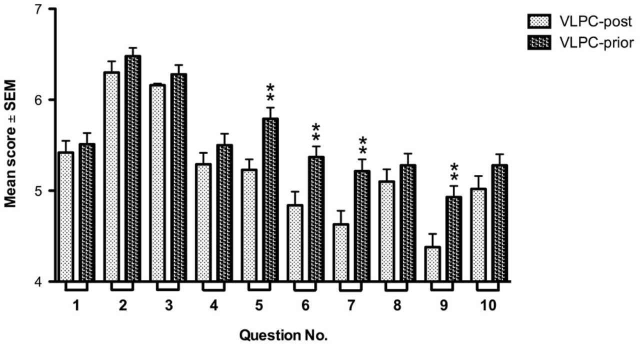

Figure 3. Effects of the VLPC on student pre-lab survey scores on perception of laboratory confidence and performance. Scores are presented as mean ± SEM, and ranged from 1 (no confidence at all) to 7 (extremely confident). The range on the ordinate is from 4 to 7 since all mean scores were greater than 4. The bars representing VLPC-prior students which contain a double asterisk indicates a statistically very significant ($p < 0.01$) increase in mean confidence scores than VLPC-post students. The questions are shown in Procedure section within the text.

VLPC-post groups. However, no decrease in these times was observed for the P5 group when compared to P2 (a VLPC-post group). This similarity prompted further analysis. Data from the VLPC server revealed that more than one-quarter of the P5 students did not attempt the online module before class, while almost all students from the P4 and P6 groups completed the VLPC prior to attendance at the laboratory. Since students worked in teams of two or three, we identified which teams did not contain any members who had completed the VLPC prior their practical class and excluded them from further analysis.

Of the 45 teams within the VLPC-prior cohort, six did not contain any "VLPC-experienced" members, and four of these were from the P5 group. Therefore, performance time data from the 39 teams of students containing at least one VLPC-experienced member was compared to the 41 teams in the VLPC-post cohort. We should also note that most of the teams in the VLPC-prior cohort contained two or three members who had completed the virtual laboratory online. Fig. 4 shows that the mean laboratory practical completion time for the VLPC-prior student teams was very significantly decreased ($p < 0.001$; mean = 100.7 min; n = 39) compared to the VLPC-post student teams (mean = 118.2 min, n = 45), and this reduction in time is approximately 17 minutes.

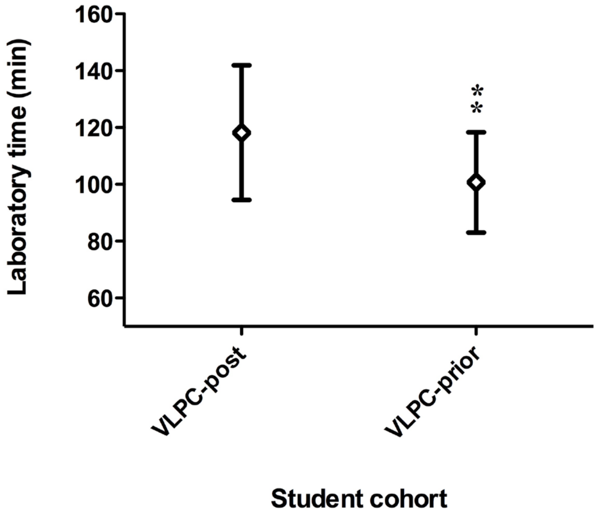

Figure 4. Laboratory practical completion times (mean ± SD) for student teams with no VLPC experience (VLPC-post) and students who were part of a team containing at least one VLPC-experienced student (VLPC-prior). Most of the VLPC-prior groups contained 2 or 3 VLPC-experienced students. The mean laboratory practical completion time for the VLPC-prior students was very significantly decreased ($p < 0.001$) compared to the VLPC-post students.

VLPC online server data

The mean active times and standard errors of the mean for each practical group were as follows: P1, 37.5 ± 2.7 min (n = 35); P2, 41.7 ± 4.0 min (n = 31); P3, 34.5 ± 3.5 (n = 35); P4, 42.6 ± 4.0 (n = 39); P5, 39.6 ± 3.8 (n = 30); P6, 37.2 ± 3.8 (n = 38). There were no statistically significant differences between any of the values for these groups. When the active times were combined for each cohort, the students who used the VLPC prior to their laboratory work spent 39.8 ± 2.0 min (mean ± SEM; n = 107) engaged with the VLPC task. Students in the VLPC-post cohort, but who were encouraged to use the VLPC resource as revision of their laboratory experience, spent 37.7 ± 2.3 min (mean ± SEM; n = 101) actively using the VLPC. There was no significant difference in the average time spent by students between the two cohorts ($p = 0.48$). The range of times spent by all students (n = 208) who engaged with the VLPC is shown in Figure 5. More than 50% of the students who used the program (111 students) were active for between 20–45 min (Fig. 5).

Students provided comments via feedback tabs that were available on each screen of the VLPC program. These comments were collected and organised by theme, and are shown in Table 1. Students were primarily critical of the lack of detailed instructions for the use of the VLPC, as well as various operational difficulties or concerns. However, the module was praised for its usefulness in preparing students for the live laboratory session, and for its realistic portrayal of the experimental task.

Post-laboratory surveys

A post-laboratory survey conducted online contained questions related to student use of the VLPC. Only

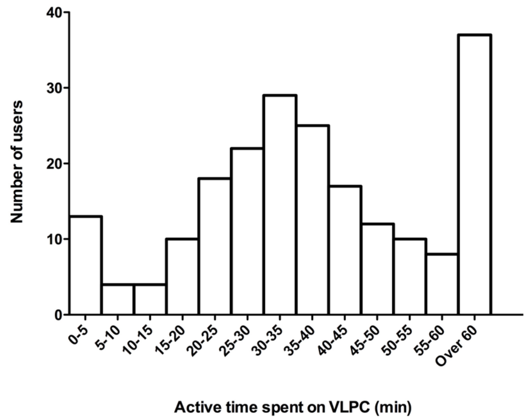

Figure 5. Amounts of time actively spent on the VLPC online. Students who dropped the course before the VLPC was made available, or enrolled students who did not engage with the program were excluded from the dataset. The mean ± SEM active times for the remaining students was 38.8 ± 1.5 min.

Table 1: A collection of negative (left column) and positive (right column) student comments acquired from the VLPC server

Instructions	Preparation
“Clearer instructions about how to go about collecting data with regard to the triple measurement button would have been helpful.” “The application would work better if there were step by step instructions throughout the procedure.” “Please give more explanations of what we are really required to do in VLPC. Students who have not conducted the experiment will be rather clueless as to what to do in VLPC as little instructions are provided.” “It was quite hard to understand what the objective of this program was initially. I think there should be a bit of an introduction actually saying that we need to use dilutions and make a concentration response curve.”	“it was actually very useful and I feel better prepared to actually perform the organ bath experiments next week.” “… I feel these virtual labs could be super important support tools for students - especially those who are not familiar with lab set ups. It could also be utilised as a preparation tool. I think it would definitely help students.” “it was a good learning experience. I thought this was a good way to get my head around what we are doing in the prac”… . “This was a very helpful program in understanding how the Organ bath works!” “It was a great introductory module to lead into the actual practicals. It gave a foundation as to what to expect during our organ bath practicals.” “I feel significantly more prepared for my practical after using this program and have an overall better understanding of the prac. I enjoyed using this platform for my preparation and think it is a great idea!”
Use of program	**Realism, usefulness and understanding**
“it was a little annoying when my pipetted solutions got pumped out when I did not intend for it to and just wanted to move the pipette to a new location.” “…a little trouble with accuracy when trying to select particular objects, especially when pipetting.” “Difficulty trying to figure out how to record contractile force values was encountered.” “It would have been good to be able to save the work done in the Virtual lab and log in later and pick up where you left off.” “Tedious to change the pipette volume.” “An undo function would be greatly appreciated.”	“…a good replicate of the real practical session”…“This simulation was quite fun, and seemed quite representative of what would happen in the real lab.” “Very user friendly, very realistic”… .“Excellent piece of software and more useful than the CALs.” “The VLPC was a very insightful and engaging activity which allowed me to understand the laboratory process of conducting an experiment using the organ bath setup. I would heartily recommend its future use for any students wishing to undertake introductory pharmacology.” “The VLPC was a really helpful online experience and will likely help me in my own practical experiment.”

VLPC-prior students (n = 46) are represented in this analysis, since the questions are all relevant to the VLPC activity occurring before their scheduled laboratory session. Therefore, we were unable to compare these findings with the VLPC-post cohort.

Students were provided with a scale from 1–7 for each question, where 1 represented “Strongly Disagree”, 4 as “Neutral” and 7 as “Strongly Agree”. The total percentile responses for all negative responses (score of 1, 2 or 3) were added, the neutral responses (score of 4) were recorded, and the percentile positive responses (scores of 5, 6 or 7) were added. The percentage positive, neutral and negative results are shown in Fig. 6.

There were a number of questions in this survey where students provided neutral or unfavourable responses. These were related to technical problems and the time needed to learn the operation of the program, which may have caused an accompanying loss of interest and engagement (Fig. 6 - VLPC use and engagement). The remaining 12 questions were either favourable or, in some cases, extremely favourable concerning the VLPC. Students were strikingly positive about the VLPC helping them prepare for, and complete, the real-life laboratory (Fig. 6 - Understanding and skills). Doing the VLPC decreased students’ perception of anxiety while boosting their confidence (Fig. 6 - Confidence and anxiety). The majority of students agreed that the video pop-ups within the VLPC were useful. Students were extremely positive in their perception of the VLPC as a realistic depiction of the real laboratory, while most were neutral

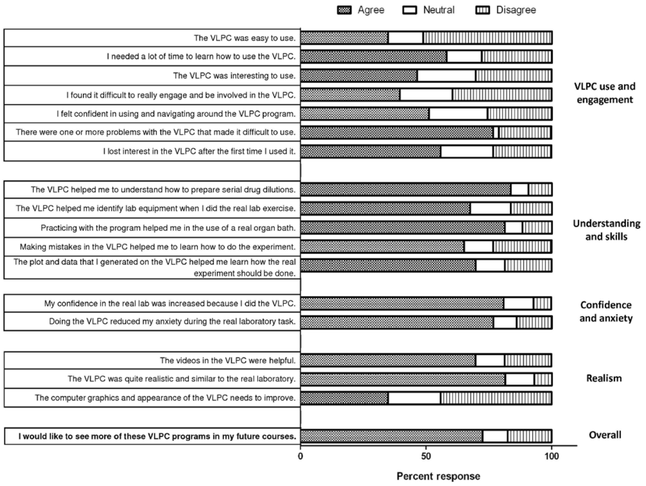

Figure 6. VLPC-prior student responses to the post-laboratory survey. Combined percentages for students who agreed, were neutral, or disagreed with the question or statement are shown in the bar graphs to the right of the relevant questions. The nature of the questions were also grouped according to themes during analysis.

or negative concerning the need for improved computer graphics (Fig. 6 - Realism). Finally, most students agreed that they would like to see more VLPC modules in their future courses (Fig. 6 - Overall).

Student assignment scores and tutor focus group session

The mean scores and standard errors of the mean for each practical group were as follows: P1, 31.1 ± 1.0 (n = 39); P2, 29.7 ± 0.8 (n = 37); P3, 27.7 ± 1.0 (n = 37); P4, 29.9 ± 1.0 (n = 39); P5, 27.0 ± 1.2 (n = 30); P6, 29.9 ± 0.8 (n = 38). There were no statistically significant differences between the groups with the exception of P5 where the mean score was significantly lower than the P1 group ($p < 0.01$). There was no significant difference between the VLPC-post (P1–P3; 29.5 ± 0.5; n = 113) and VLPC-prior (P4–P6; 29.1 ± 0.6; n = 107) cohorts ($p = 0.88$). The Pearson correlation coefficient between the assignment scores and the amount of student active time on the VLPC was determined ($r_p = –0.013$), confirming a lack of relationship between these two variables.

DISCUSSION

The VLPC experience resulted in a significant decrease in both the average time and the level of variance in times that students took to complete their laboratory tasks. The tutors generally agreed that fewer students were "lagging behind" in practical groups containing students with prior VLPC experience. Consistent with this result, Payne et al. (2008) showed that an animated laboratory computer simulation package could "bridge the gap" between expert and novice student users through the transfer of practical and analytical skills by means of their virtual laboratory. Other reports also show data indicating that direct improvements in student performances in the real laboratory can be made through the implementation of virtual pre-laboratory exercises. For example, there were decreases in both the mean and variance laboratory completion times for students who received a pre-laboratory 'chromosome analysis' computer-based simulation (Gibbons et al., 2004), a hematocrit blood analysis web-based simulation was found to enhance the actual performance and consistency of performances of students in laboratory sessions (Moreno-Ger et al., 2010), and use of a biochemical engineering virtual laboratory resulted in significant enhancements in hands-on student laboratory performances (Domingues et al., 2010). As with our findings, these indicate the effectiveness of virtual laboratories as remedial and standardizing tools that may be especially beneficial to students who encounter difficulties in performing laboratory-based tasks.

The VLPC server data revealed that up to one-third of the VLPC-prior students spent less than 20 minutes in active engagement with the module. It is possible that these students had prior knowledge of the VLPC by watching other classmates perform the task, thus allowing them to complete the task quickly. However, it is also possible that many of these students were not motivated to engage with the program and simply submitted with little or no data. Data from the post-laboratory survey also showed neutral or negative student responses for the VLPC 'use and engagement' questions. There were several software technical problems (program crashes, and a minor glitch with the use of Eppendorf tubes), as indicated by some of the student feedback comments. Although these were remedied quickly, this may have resulted in some student difficulty in the use of the program. Also, many students reported that a lot of time was needed to learn the program which may have contributed to a loss of interest and engagement. More detailed instructions, as requested in student feedback comments, are expected to alleviate this problem. This has been emphasised in a previous report using a pharmacology computer simulation (Wang, 2001). Requests that progress within the virtual laboratory be saved so that it can be restored after leaving and re-entering the VLPC are also being addressed. The importance of having a "savepoint" such as this has been discussed in a previous study (Prieto-Blazquez et al., 2008). We plan to incorporate this in future versions.

High-definition videos were included in the virtual lab, since they have been shown to increase student confidence in laboratory techniques (Maldarelli et al., 2009). This feature was reported as useful by the VLPC-prior students in the post-laboratory survey. Yu et al. (2010) embedded video presentations into their virtual immunology laboratory, where students agreed that the video-based format was an effective way of demonstrating the laboratory procedures, especially when mistakes were made in the virtual task. However, we should note that the usefulness of the videos in our study would likely to be lower for those students who have already completed the laboratory task (i.e. the VLPC-post cohort), although we did not conduct post-laboratory surveys with these students. We intend to undertake further studies that more closely examine student engagement with videos within virtual laboratories.

No significant differences were observed between the VLPC-prior and VLPC-post cohorts for the first 4 questions in the pre-laboratory survey. These questions related to calculation of drug dilutions and basic pipetting skills, as well as a question concerning transfer of raw data to graph construction. The lack of effect of the VLPC on responses to these questions may be explained by students' past experience with these standard calculations and skills during work in previous courses. Most students have already completed a major first-year biology course, which contains a series of practical sessions comprising a large component of the course. Students are trained in the use of pipettors and are required to complete calculations and construct graphs, and thus the VLPC may be of no further benefit to students for these tasks. This suggests that a ceiling effect was observed with these questions, minimising VLPC-mediated increases in the student perception data. Interestingly, no improvement in the perceived ability to explain the purpose of the laboratory experiment was observed. This may be because the VLPC was not intended to address verbal communication skills, and thus could not enhance student confidence in explaining the experiment to other students. In contrast, our findings suggest that the VLPC can increase student familiarity and confidence with equipment and protocols that are new to them, affording them a significantly greater preparedness for the real laboratory experiment. This is in accordance with previous studies which show that virtual laboratories can serve as preparatory tools by increasing student familiarity with laboratory apparatus and their experimental use (Dalgarno et al., 2009). Koretsky and colleagues (2008) also showed that the overwhelming majority of students agree that a virtual laboratory generally assists them in preparing for live practical sessions. Positive feedback responses on the VLPC assisting their preparation also supported these findings.

There are a considerable number of reports that show that pre-laboratory virtual simulations can improve student assignment and test scores (Goldberg & Dintzis, 2007; Evans et al., 2008; Koretsky et al., 2008; Abdulwahed & Nagy, 2009). We found no difference in assignment scores between the VLPC-post and VLPC-prior cohorts. Indeed, statistical analysis revealed that there was no correlation between assignment scores and the amount of active time spent on the VLPC. Tutors reported large variations in student marks within assessment criteria that were unrelated to the VLPC (e.g. written communication skills, construction of Tables and Figures). It is possible that this may have confounded attempts to properly determine any effects of the VLPC on student assignment performances. This reasoning is not, however, based on the statistical analysis of the scores comparing the six P groups. Furthermore, the P5 group (a VLPC-prior group) actually scored significantly lower on assignment scores than one of the VLPC-post groups (P1), even though the amount of active time spent by this group on the VLPC was similar to the other groups. Further studies are required to more rigorously assess the effects of virtual laboratories such as the VLPC on student assessment, with emphasis on the statistical analysis of the data. We envisage undertaking future work involving the design of a virtual laboratory module that focuses more specifically on improving student assignment and examination scores.

In the post-laboratory survey, many students reported increases in their confidence, reduction of anxiety, and a better understanding of core practical skills. This supports earlier perception data acquired using a pharmacology computer-simulated laboratory (Wang, 2001). Students also indicated the importance of practicing with the program before the real laboratory session, a feature that has been recognised as an advantage of pre-laboratory virtual modules (Toth, Morrow & Ludvico, 2008). In addition, they appreciated the importance of making mistakes in helping them learn, suggesting that they are engaging in self-reflective practices, a feature crucial to the learning process (Veal, Taylor & Rogers, 2009). Students also reported an improved interpretation of the data arising from their use of the VLPC prior to the real experiment.

Post-laboratory survey data indicated that most students regarded the VLPC as realistic and similar to the real laboratory. Positive student comments provided via the browser provided further evidence of this. This suggests that the program is providing an environment that students regard as consistent with what they observe in the teaching laboratory. Koretsky et al. (2008) have shown that students perceived their chemical engineering virtual laboratory as a 'real' physical laboratory. Interestingly, we discovered that students placed a low level of importance on the need for improvements in the level of computer graphics and appearance of the VLPC. Wolf (2010) has recently published a study on the effectiveness of virtual laboratories, and states "realism is probably the most important quality of a laboratory when it comes to student learning". We also expected students to place a high value on the realism of virtual laboratories, in both its functional and visual capacities.

To summarise, the use of the VLPC improves student confidence and skills in the live laboratory setting, and reduces experimental completion times. These outcomes are valuable, despite the lack of effect of VLPC engagement on assessment scores. While this and several other shortcomings of the VLPC have been identified, our findings do strongly suggest that it is a good platform from which to embark on future virtual laboratory projects. Indeed, the vast majority of students showed an interest in seeing more VLPC modules in the future. Upcoming studies will be geared towards new modules that include different experiments with significantly enhanced graphical and intuitive properties, and which can lead to increases in student assessment scores.

ACKNOWLEDGMENTS

A Faculty of Science Teaching & Learning Strategic Grant at the University of Queensland supported the work for this project. The authors wish to acknowledge John Zornig, Prof Alan Cody and Prof Phil Long, from the Centre for Educational Innovation and Technology at the University of Queensland, for their guidance and support in the development of the project, and Nadia Chester in CEIT for her assistance in the graphical design.

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