Higher Education Pedagogies

ISSN: (Print) 2375-2696 (Online) Journal homepage: https://www.tandfonline.com/loi/rhep20

# Evaluating the benefits of virtual training for bioscience students

Sarah K. Coleman & Caroline L. Smith

**To cite this article:** Sarah K. Coleman & Caroline L. Smith (2019) Evaluating the benefits of virtual training for bioscience students, Higher Education Pedagogies, 4:1, 287-299, DOI: 10.1080/23752696.2019.1599689

**To link to this article:** https://doi.org/10.1080/23752696.2019.1599689



Published online: 10 Oct 2019.

HIGHER EDUCATION PEDAGOGIES
2019, VOL. 4, NO. 1, 287–299
https://doi.org/10.1080/23752696.2019.1599689

OPEN ACCESS Check for updates

# Evaluating the benefits of virtual training for bioscience students

Sarah K. Coleman and Caroline L. Smith

School of Life Sciences, University of Westminster, London, UK

**ABSTRACT**

Virtual laboratory simulations are commercially available to train students; these creative resources are available to complete remotely without traditional time and safety restrictions of laboratory-based practical classes. We introduced a Health and Safety virtual laboratory simulation to a core large first-year science module. Having surveyed students using a combination of Likert-type responses, multiple answer questions and free text responses, students reported that it had increased understanding and knowledge. Additionally, students reported that the laboratory simulation was motivating and had increased confidence for actual practical classes. We also surveyed students one year after completing the simulation finding a similar pattern of responses; the simulation had been useful, increasing confidence and knowledge about Health and Safety. Our data show that the virtual laboratory simulation improved student understanding and was still perceived to have been useful one year after completion, providing evidence of a longer term impact of the simulation on student learning.

**ARTICLE HISTORY**
Received 27 July 2018
Revised 12 February 2019
Accepted 6 March 2019

**KEYWORDS**
Laboratory simulation; virtual training; Labster; Health and Safety; bioscience

## Introduction

There is an expectation that all students will have suitable skills for employment upon graduation and Higher Education institutions are measured against this criterion in the Teaching Excellence Framework (Department for Business, Innovation & Skills, 2016). An essential skill for science students is the technical ability to plan and perform a range of scientific experiments, interpret the data generated and communicate the findings. Evidence of these skills is required by professional bodies including the Royal Society of Biology and assists prospective graduate employers. The idea that students should learn in a real-life situation by doing and practising skills is not a new one (Dewey, 1916). Thus, all students on a science course should have the opportunity to undertake practical classes, to enable this, institutions should have adapted laboratories to accommodate the disability needs of students (Brown, 2016), which may include, but is not limited to, wheelchair access, having support workers present, support for hearing or visually impaired students. Occasionally, however, unforeseen circumstances

**CONTACT** Caroline L. Smith C.Smith24@westminster.ac.uk School of Life Sciences, University of Westminster, 115 New Cavendish Street, London W1W 6UW, UK

or a condition may prevent a student from attending a practical class, such as teratogenic risk in pregnancy.

With large class groups in Science, Technology, Engineering and Mathematics (STEM) subjects there are pressures on space available in laboratories, the reagents and equipment availability meaning that often students work in small groups (of two – three) and this creates a challenge to evaluate if laboratory skills have been assimilated by students. Further, we have observed that in large practical laboratory classes with large numbers of students, there are students who are unwilling take part, and if working in pairs or small groups will defer to other members of their class/group or will be less engaged in undertaking practical techniques. There may be several reasons attributable to this behaviour, these are likely to include the prior educational experience of experiments and personal confidence (Adams, 2009; Wood, 2009).

A crucial step in undertaking experiments in the laboratory is the risk assessment of the procedures and the potential chemical hazards; as laboratories contain hazardous chemicals and expensive equipment access is controlled and restricted to specific hours with technical or academic staff present, this is in contrast to many higher education resources such as libraries and computer rooms. The potential hazards, expense and time limitation increase pressure on students to not make mistakes, which may discourage participation. The use of virtual laboratories overcomes many of these issues – indeed students can be encouraged to 'make mistakes' to examine the consequences (Cann, 2016).

The introduction of virtual laboratories overcomes traditional issues of health as safety, allows round the clock access and is potentially more suited to distance learning students. In a virtual environment, a student can use highly specialised equipment and reagents without impacting a research budget and enables a student to make mistakes in the controlled environment which will not have adverse cost or safety effects and provide a more inclusive environment for a diverse range of students. A number of studies have suggested that the chance to redo tasks/rewatch instructions enhances understanding of underlying principles (Cann, 2016; Polly, Marcus, Maguire, Belinson, & Velan, 2014; Pyatt & Sims, 2012). However, concerns have been raised that the nature of a virtual system may create a student attitude where there is a lack of seriousness, responsibility or carefulness (Potkonjak et al., 2016). The level of the virtual simulation needs to be suitable; if too complicated, students will become discouraged and not complete the task, but if the task is too easy, students may lose interest (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). However, Pyatt and Sims (2012) suggest virtual simulations can enhance learning when appropriately targeted.

A previous study compared forensic students who used a virtual laboratory simulation based on a case study to those who had a traditional lecture and tutor lead exercise, the study reported that up to 40 days after the virtual simulation the group had significantly improved learning outcomes (Bonde et al., 2014). Other studies have highlighted the need to look at the longer term impact of virtual simulations (Makransky, Thisgaard, & Gadegaard, 2016a; Makransky et al., 2016b); therefore, this study has considered this requirement. Deeper learning and assimilation of knowledge is important for bioscience students and thus an aim of this study was to look at students 12–13 months after participation in virtual simulations to investigate if these students perceived the simulations differently and to determine if there was any long-term memory from the simulation.

Aims: This study aims to see how students perceive virtual laboratory simulations using a combination of Likert type responses and free text questions:

(1) immediately following completing a simulation,
(2) a couple of weeks after completing the simulation,
(3) one year after completing the simulation.

## Methodology

In order to capture the viewpoints of as many students as possible who engaged with the virtual simulations as possible; mixed methods approach was used firstly a quantitative approach where students were given statements within a survey and asked to respond with likert-type responses (Likert, 1932) surveys which could be made available to the whole cohort of students. Secondly, qualitative data was also collected in the form of free-text comments, so that students had an opportunity to reflect more widely on the impact of these simulations and to potentially identify new areas of interest or concern which had not been captured by the Likert-type responses.

## Methods

### *Ethical approval*

This study received approval from the University of Westminster, Faculty of Science and Technology ethics board (application ETH1718-0079).

### *The simulation*

The commercially available Labster™ virtual simulation was chosen to add creativity to the process of training students in health and safety in a large first-year core Biochemistry module over a period of two academic cycles. This simulation introduces students to a laboratory and includes hazardous scenarios so students have opportunities to recognise these hazards and learn how to overcome them. To progress through the simulation students must complete a series of multiple answer questions and a running score is visible to the student at the top of the screen (Figure 1). On the virtual tablet the students use to complete the questions in the laboratory simulation, there are tabs for further theory (theory), animations (media) and links back to the main task (mission) (Figure 1). This simulation was chosen over other commercial simulations because the student is encouraged to make mistakes, have an accident and see the consequences, scenarios which would be highly dangerous in a real laboratory.

The main learning outcomes in this Labster™ virtual simulation were:

- Learning how you should be dressed for a day in the lab
- Figuring out the do's and don'ts in a laboratory
- Learning when and how to use the lab safety equipment
- Reacting in an emergency situation

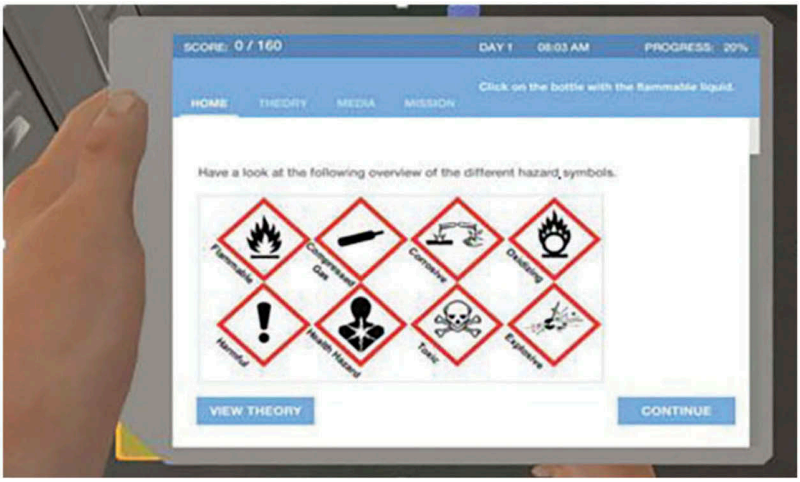


**Figure 1.** Screenshot of the hazard symbols displayed to students as part of the Labster™ Health and Safety simulation. In this image, it is also possible for the students to see their progress within the simulation and score at the top of the screen. From Labster™ (reproduced with written permission).

## *Sample*

The sample consisted of first and second-year bioscience students at a UK university entry years 2016–17 (347 students) and 2017–18 (384 students), who were taking the core undergraduate biochemistry module (see Table 1). Their degree pathways were BSc Biochemistry, Biological Sciences, Pharmacology and Physiology, Human Nutrition, Herbal Medicine, Biomedical Sciences and Applied Biomedical Science.

## *Procedure*

In years prior to the introduction of the simulation students were given a health and safety briefing in orientation week and then received briefings at the start of the first practical class (week 4). Following the introduction of the simulation (2016–17), students still received the orientation week briefing but were encouraged to complete the simulation between teaching weeks 1–4 (prior to their first practical class). Students have to log on to complete the simulation, so it is possible to determine which students have completed the simulation and their score. Students were permitted to repeat the simulation if they wished.

**Table 1.** Summary of the participant who completed each survey in 2016–17 and 2017–18, respectively.

| | Survey 1 completed by | Survey 2 completed by | Survey 3 completed by |
|---|---|---|---|
| 2016–17 entry ($n$ = 347) | 1st year of studies; all bioscience students who completed simulation ($n$ = 196) | 1st year of studies; voluntary survey open to all bioscience students ($n$ = 73) | 2nd year of studies; voluntary survey open to all bioscience students ($n$ = 76) |
| 2017–18 entry ($n$ = 384) | 1st year of studies; all students who completed simulation ($n$ = 151) | 1st year of studies; voluntary survey open to all bioscience students ($n$ = 49) | Not applicable |

Three surveys were deployed (please see below):

Survey 1 'Immediate Feedback Questionnaire directly following completion of the Labster$^{TM}$ simulation'. First-year students were presented with the questionnaire immediately upon completion of the simulation, and it appeared within the simulation (Likert-type responses, Likert, 1932).

Survey 2 'Online questionnaire on clarity of content and perceived usefulness of Labster$^{TM}$ simulation'. This survey was available to first-year students online and promoted in subsequent tutorials, approximately two weeks following completion of the simulation (Likert-type responses including ability rating and free text responses).

Survey 3 'One year follow-up on student evaluation of Labster$^{TM}$ simulation'. This survey was given to second-year students to complete online, this was one year after students initially completed the simulation (Likert-type responses, multiple choice questions and free text responses).

Completion of the surveys and the simulation itself were highly encouraged but were neither formally timetabled as an activity nor made a component of a summative assessment.

## Results

In total 347 students completed both the Labster™ Health and Safety simulation and the immediate feedback survey (Survey 1), out of a cohort of 731 students (47.5% completion rate; combined 1$^{st}$ year bioscience students from 2016–17 and 2017–18 entry cohorts). Of the students who completed the simulation and questionnaire over 91% of them agreed or completely agreed with the following five statements: that they were pleased by the simulation; that it had helped their understanding of a real-life scenario; they were more confident in the laboratory; found the simulation motivating; and had gained relevant knowledge (Figure 2).

In order to understand which aspects of the simulation had appealed to students, a second survey was provided (Survey 2). This was deployed two weeks following the Labster$^{TM}$ simulation, completion of this later survey was voluntary. This considered the Learning Objectives of the simulation and their alignment to the module, student conception of the simulation content and organisation, the pace of progression through the simulation, whether the time to undertake the simulation was appropriate, if the students had gained suitable skills or knowledge and whether the virtual simulation had been beneficial to student learning. The data are presented in Figure 3. Students either agreed or strongly agreed with these statements, although there was a less positive response to the statement 'Time taken to complete the Virtual Practical (VP) was appropriate'. Students report that they find the simulations interesting and that the simulations have enhanced understanding.

Within this second survey, students were asked to self-rate their knowledge about health and safety before completion and after completion of the Labster™ simulation (Figure 4). Before completing the survey, most students had self-identified that their knowledge was satisfactory or very good (66.7%); after the simulation, this had shifted so that the majority of students (79.5%) self-assessed their knowledge as very good or excellent. It is possible that completing the simulation has improved the confidence of these students, as well as, their knowledge so that they self-assess more positively. However, we would argue that

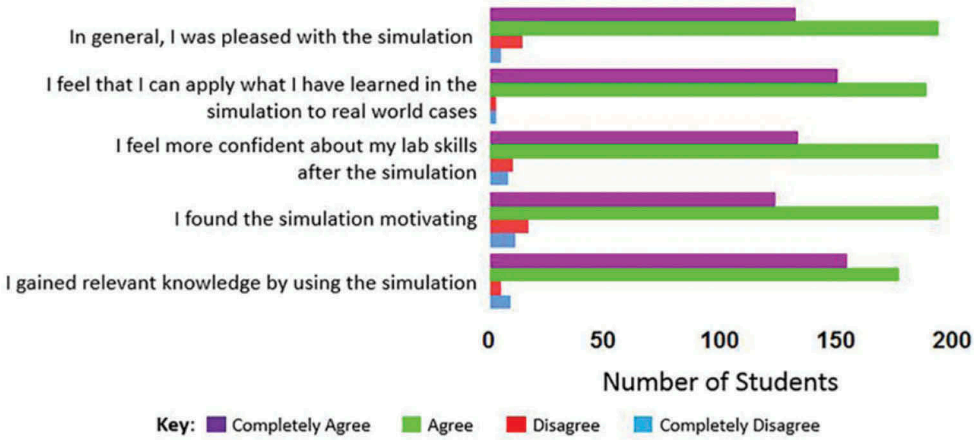


Figure 2. Survey of students' experience immediately following completion of Labster™ Health and Safety simulation. Frequency of student response to the given questions in Survey 1. Students were first-year undergraduates on a range of bioscience degree pathways (see methods) attending the core first-year biochemistry module. Data combines responses from entry cohorts years 2016–17 (n = 196) and 2017–18 (n = 151), n = 347.

increased confidence is also beneficial, since students are more likely to participate in laboratory activities in future sessions. The above is reinforced by overall positive free-text anonymous comments from the students, a sample of these is shown below:

> *Useful for practice but I still believe we should actually go into the lab and use a hands on approach.*
> *Good way to understand experiments virtually*
> *It's useful when preparing for laboratory experiments*
> *Useful as a practice before doing a practical. The virtual activities should also be done physically so the concepts are put into practice.*
> *Very time consuming and does not equip you sufficiently for real life lab work*
> *I honestly don't know why people don't like it*
> *It is an amazing tool to provide laboratory simulation to the students*
> *Brilliant to refresh past lab experience and essential for those who have had little to no prior laboratory experience.*
> *Highly interactive, very useful way of refreshing previous knowledge, interesting how the simulation showed you what would happen if things went wrong.*
> *lab safety. learning what procedure is correct to follow in case of: a fire, spillage, etc. My confidence to work in the lab has increased*

To investigate the longer term perceptions of the Labster™ simulation, students in a core 2nd year module for all bioscience undergraduate courses were invited to complete a survey (Survey 3) about their experiences of the Labster™ simulation they completed in their 1st year (Figure 5, black bars shows the responses of students in their second year next to the responses from the same cohort in their first year). This voluntary 2nd year survey examined student perception of laboratory simulation usefulness and information learned (76 students completed it). At this stage, students would have attended many practical classes, tutorials and lectures and would have taken the Biochemistry 1st year practical exam. This survey indicated that 76% of the students

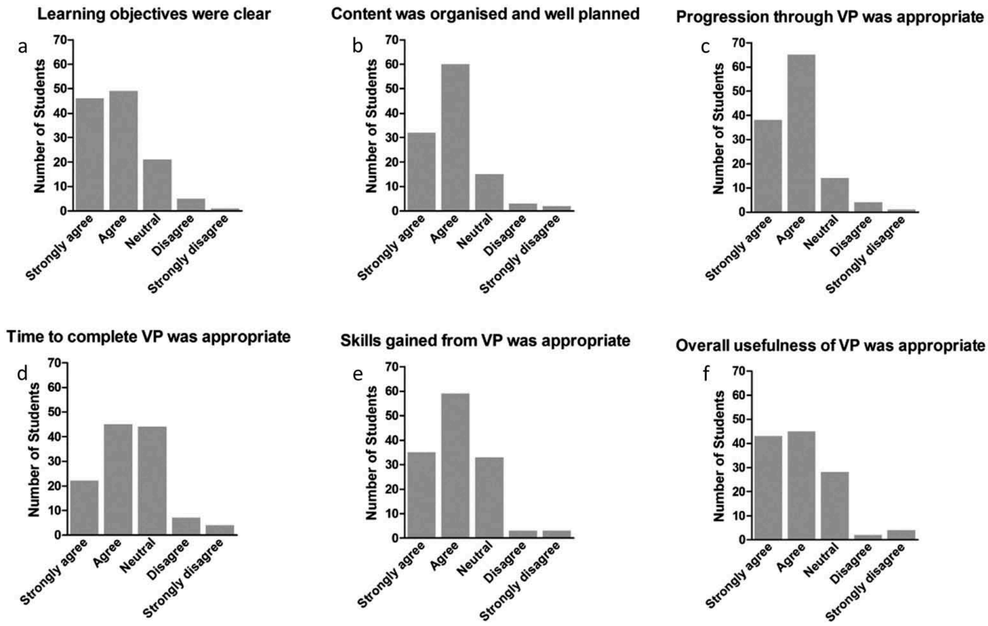


Figure 3. Survey investigating student opinion on specific aspects of Labster™ Health and Safety simulation two weeks after completing the Labster™ simulation. Graphs A–C examine clarity of content; Graphs D-F examine the level of effort and perceived the usefulness of the simulation. Survey 2 was provided online following a tutorial session, completion of the survey was voluntary. Graphs show the frequency of student response to the given questions. All surveyed students were first-year undergraduates on a range of bioscience degree pathways attending the core first-year biochemistry module. Data combines responses from two entry cohorts, 2016–17 (n = 72) and 2017–18 (n = 49), n = 122 (from a total of 731 students registered to the module).

were either confident or very confident that they would know what to do if a chemical splashed in their eye and only 11% were not very confident about what to do; no student self-reported not knowing what to do at all. A potential limitation of this survey is that some students who did not complete the survey in their first year of studies may have completed the second year of studies survey. Further, the Survey 3 question regarding perceived usefulness of the simulation was not testing knowledge directly. Therefore, a multiple choice question about chemical hazard symbols was also included in Survey 3. The Labster$^{TM}$ Health and Safety simulation shows eight hazard symbols (Figure 1), during the completion of the simulation students were asked to identify the symbol for a flammable liquid. When surveyed a year after completing the simulation we asked students to identify the oxidising symbol; 90% of the respondents correctly recognised this symbol.

As Figure 5 indicates students in their 2$^{nd}$ year of studies still perceive the Labster™ Health and Safety simulation to have been useful one year after initially completing the simulation. It is notable that the pattern of responses about the usefulness of the simulations in the second year was very similar to that seen when this cohort were laboratory naïve 1$^{st}$ year students.

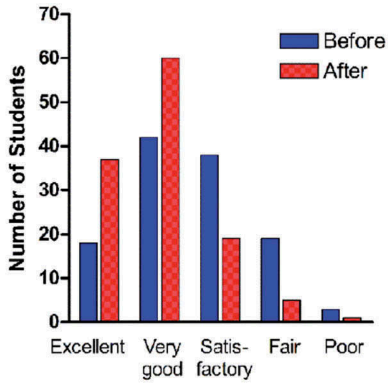


Figure 4. Student self-evaluation of knowledge of Health and Safety before and after the Labster™ Health and Safety simulation. Students were asked to self-assess their level of health and safety knowledge before and after completing the simulation. Survey 2 was provided online following a tutorial session. Graphs show the frequency of student response. All students were first-year undergraduates on a range of bioscience degree pathways attending the core first-year biochemistry module. Data combines responses from entry cohorts years 2016–17 (n = 72) and 2017–18 (n = 49), n = 122 (from a total of 731 students registered to the module).

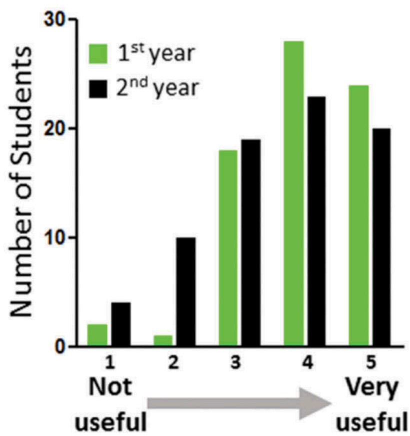


Figure 5. Comparison of student evaluation of virtual simulation usefulness to learning after the simulation in 1st year and 1 year after the simulation in their second year. Students were asked to self-assess their how useful they perceived the virtual simulations; range, 1 = not useful through to 5 = very useful. Responses are from 1st year students (of cohort entry 2016–17; n = 73; green columns) and then the same cohort was asked to complete the survey in their 2nd year (2017; n = 76; black columns) of studies. The difference in n values corresponds to students who had direct entry to 2nd year from other institutions. Survey 3 was provided online following a contact teaching session and advertised through the virtual learning environment. Graphs show the frequency of student response. All students were university undergraduates on bioscience degree pathways.

## Discussion

We report that most students have found the simulations to be interesting, and these simulations have prepared them for practical work, this is seen in both the immediate and later surveys. Students were asked to evaluate what they knew *about health and* *safety* before completing the simulations and then how much they considered they knew having completed the simulation, there was a clear rightward shift post-simulation reflecting that the students had a greater understanding. Students reported that the learning outcomes of the virtual simulation were appropriate for learning about health and safety. In the Likert responses, students agreed with the statements that the simulations had increased their understanding and confidence for laboratory work; consistent with the meta-analysis done on virtual simulations in science, engineering, medicine and maths disciplines (Merchant et al., 2014).

We are confident that where students have worked through the virtual simulations this has increased their understanding and confidence as reported in the surveys. However, one of the issues noticed in this study was student engagement with this formative task. This study has recorded consistent student responses to the simulations over two academic cycles. However, in both cycles students had the option to complete, or not, the simulation as it was a formative assessment and not compulsory. Thus, in 2016–17, 57% of the students completed the Labster™ simulation and in 2017–18, 39% of the students completed the simulation. These percentages values contrast with the engagement on another of our institution's core first-year module with the same cohort of students. That module used LearnSmart™ the virtual laboratory simulations provided by the company MacGraw-Hill. Moreover, in this module completion of the simulations contributes to a summative portfolio mark. Within this module where completion of virtual simulations contributes to summative assessment, the student engagement with the virtual laboratory simulations is above 90%. The higher participation rate for the summative activity with the same cohort of students would argue against student 'digital literacy' being a cause of low engagement (Morris, Ramsay, & Chauhan, 2012).

Given that the majority of students report that the simulations have increased understanding, this would provide evidence that the simulations have benefited students and therefore further consideration could be given to incorporating the simulation into a summative assessment. However, formative assessment exercises enable students to develop independence and take control of their own learning (Nicol & Macfarlane-Dick, 2006). It has previously been observed that students with low knowledge prior to participating in a virtual laboratory simulation reported greater gains in knowledge than those who had been identified to have moderate or very good existing knowledge (Makransky et al., 2016b).

In our study students needed to register with Labster™ in order to access the simulation, there were a few technical glitches with this process which were reported to the module leader and in the free text survey questions. A recent development from that time is that the Labster™ simulations can be integrated with Virtual Learning Environments (we use Blackboard). Being able to see the completion of virtual simulations on the Grade centre facility is possibly a motivating factor for students to complete these simulations and could be an area for further research.

An advantage of virtual simulation is that students can access the simulation 24 h a day, this greatly improves accessibility and enables the student to plan their studies without the rigorous scheduling of traditional practical classes. Other researchers have commented that virtual simulations might encourage students to approach a scenario with less care or seriousness (Potkonjak et al., 2016). This was not apparent in our study. If the student is getting a meaningful learning experience, and if the simulation is used before an actual laboratory session, the virtual simulation can enhance the participation and learning (Barko & Sadler, 2013; Pyatt & Sims, 2012).

As previously mentioned the authors have noticed that in large class practicals where students are working in groups there are frequently students who do not seem to be as actively involved in the practical, relying on their group to carry out the work. There is significant diversity in the student body with some students having little experience of laboratory-based work prior to commencing on the bioscience degree programs. The results from these surveys, following use of the virtual simulations, indicate that the simulations have boosted confidence (Survey 1); this may encourage greater student participation in practical classes. This is also highlighted in the free text comments from Survey 2.

*'My confidence to work in the lab has increased'*

Within the simulation, the student moves around the virtual lab and is only portrayed on screen as a hand. At the start of the simulation, a young woman is the character, there is evidence to suggest that where students can personalise aspects of the avatar their engagement in simulations increases (Economou, Doumanis, Argyriou, & Georgalas, 2017). Within a laboratory setting long, loose hair is considered a safety risk due to open flames from Bunsen burners, chemicals and microbes on benches and risk of contamination. Standard laboratory guidelines include tying back loose hair, an option to personalise the character in this simulation might help to emphasise this specific risk.

One student provided a negative comment about the simulation commenting that it was *'Very time consuming and does not equip you sufficiently for real life lab work'*. It is worth noting in Figure 3(b) that there is a leftwards neutral shift when students were asked about the amount of time needed to complete a simulation. However, analysis of the time students spent on Labster™ Health and Safety simulation yielded the median times of 18 min and 13 min for the entry cohorts 2016–17 (n = 267) and 2017–18 (n = 196), respectively.

However, another student comment was *'I honestly don't know why people don't like it'*, which suggests that this student was aware that peers had been negative towards the simulation. Another student thought that *'It is an amazing tool to provide laboratory simulation to the students'*. From the free text comments, it is clear that students do not want virtual labs to replace real labs but can see a benefit of virtual laboratory simulations. Whilst overall the student experience of virtual labs has been positive, it is certainly clear from the free text comments that the students see the simulations as a tool to familiarise themselves with the practical and to prepare for the practical classes. They do not suggest that the simulations should be used to replace actual practical classes, this is in contrast to the previous findings of Polly et al. (2014), Pyatt and Sims (2012). The simulations are a creative tool to deepen understanding and increase the confidence of students to prepare them for laboratories. They are not being proposed replacements for practical classes. It has previously been reported that the availability of both virtual and actual laboratories enhances student engagement and learning (Cann, 2016; Polly et al., 2014; Pyatt & Sims, 2012; Scheckler, 2003).

A key aim of teachers is to promote deeper learning within their classes. Previous reports have looked at the use of a Crime Scene virtual laboratory simulation and compared it to a traditional lecture and exercise, both groups were then presented with a summative test, the researchers looked at the effects of the simulations up to 40 days after having completed them (Bonde et al., 2014). Our research aimed to see if there were longer term impacts on student learning by surveying students one year after completion of the simulation.

When investigating the longer term impacts of the Labster™ Health and Safety simulation, it was recognised that students could under or overestimate their confidence with Health and Safety or their ability on how to respond to the situation of a chemical splashing in their eye. However, the researchers thought a question identifying a specific chemical hazard provided less opportunity to over or underestimate skills. Surprisingly 90% of the students correctly identified the oxidising reagent symbol, we consider that this is not a commonly or ubiquitously seen chemical hazard symbol, thus an appropriate test of subject knowledge.

First-year students were asked to rate the Labster™ simulations for usefulness, and then a year after having completed these simulations, students rated the simulations similarly. Students in their 2nd year of studies would have had numerous practical classes, tutorials and lecture sessions, and they self-reported that these resources, as well as textbooks, had informed their health and safety knowledge; thus it was surprising that a year after having completed the Health and Safety simulation, these students also self-reported that they still perceived the simulation to have been being useful or very useful. It has been previously reported that games in a variety of disciplines had an effect on longer term learning (Merchant et al., 2014). Here we provide evidence that the use of Virtual Laboratories simulations is also having a longer term impact on student learning.

We would recommend that virtual simulations are beneficial to student learning when the learning outcomes are well aligned with the specific module and wider aspects of a degree. Ensuring students have easy and reliable access to any simulation aids in eliminating student tensions which may demotivate students from completion. We would suggest that virtual simulations are more useful for knowledge and preparation rather than replacement of practical elements.

A caveat of the current study is of the self-selective nature of the student participation; thus, it is possible that only motivated students engaged with the simulations and completed the surveys. Further, the majority of this study focuses on student perception, rather than objective measures of attainment. However, we would argue that especially in large first-year intakes, boosting student confidence and improving the perception of the overall teaching environment is important in student retention.

## Conclusion

In conclusion, virtual simulations have increased student reported interest and confidence. The ability to allow deliberate mistakes and accidents in virtual simulations can leave a vivid impression of consequences. Virtual simulations provide long-term impact on student learning and engagement with flexible access and thus are an important tool in the modern learning environment. A limitation of this study is a likely bias towards the more motivated and engaged students who voluntarily completed the Labster™ simulations and surveys.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by the Quintin Hogg Trust [Labster_CB110900].

## ORCID

Sarah K. Coleman http://orcid.org/0000-0002-1066-8296
Caroline L. Smith http://orcid.org/0000-0002-5217-6812

## References

Adams, D.J. (2009). Current trends in laboratory class teaching in University Bioscience Programmes. *Bioscience Education*, *13*(1), 1–14. doi:10.3108/beej.13.3

Barko, T., & Sadler, T.D. (2013). Practicality in virtuality: Finding student meaning in videogame education. *Journal Science Education and Technology*, *22*(2), 124–132. doi:10.1007/s10956-012-9381-0

Bonde, M.T., Makransky, G., Wandall, J., Larsen, M.V., Morsing, M., Jarmer, H., & Sommer, M. O. (2014). Improving biotechnology education through simulations and games. *Nature Biotechnology*, *32*(7), 694–697. doi:10.1038/nbt.2955

Brown, E. (2016). Disability awareness: The fight for accessibility. *Nature*, *532*, 137–139. doi:10.1038/nj7597-137a

Cann, A.J. (2016). Increasing student engagement with practical classes through online pre-lab quizzes. *Journal of Biological Education*, *50*(1), 101–112. doi:10.1080/00219266.2014.986182

Department for Business, Innovation & Skills. 2016. Higher education: Success as a knowledge economy – White paper. Cm. 9258. London: Williams Lea for HMSO. Retrieved November 25, 2018, from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523546/bis-16-265-success-as-a-knowledge-economy-web.pdf

Dewey, J. (1916). *Democracy and Education*. New York: The Free Press (1966).

Economou, D., Doumanis, I., Argyriou, L., & Georgalas, N. (2017). User experience evaluation of human representation in collaborative virtual environments. *Personal and Ubiquitous Computing*, *21*(6), 989–1001. doi:10.1007/s00779-017-1075-4

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, *140*, 1–55.

Makransky, G., Bonde, M.T., Wulff, J.S., Wandall, J., Hood, M., Creed, P.A., & Nørremølle, A. (2016b). Simulation based virtual learning environment in medical genetics counseling: An example of bridging the gap between theory and practice in medical education. *BMC Medical Education*, *16*, 98. doi:10.1186/s12909-016-0620-6

Makransky, G., Thisgaard, M.W., & Gadegaard, H. (2016a). Virtual simulations as preparation for lab exercises: Assessing learning of key laboratory skills in microbiology and improvement of essential non-cognitive skills. *PloS one*, *11*(6), e0155895. doi:10.1371/journal.pone.0155895

Merchant, Z., Goetz, E.T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T.J. (2014). Effectiveness of virtual reality-based instruction on students‘ learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29–40. doi:10.1016/j.compedu.2013.07.033

Morris, N.P., Ramsay, L., & Chauhan, V. (2012). Can a tablet device alter undergraduate science students' study behaviour and use of technology? *Advances in Physiology Education*, *36*(2), 97–107. doi:10.1152/advan.00104.2011

Nicol, D.J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education*, *31*(2), 199–218. doi:10.1080/03075070600572090

Polly, P., Marcus, N., Maguire, D., Belinson, Z., & Velan, G.M. (2014). Evaluation of an adaptive virtual laboratory environment using Western Blotting for diagnosis of disease. *BMC Medical Education*, *14*, 222. doi:10.1186/1472-6920-14-222J

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Gütl, C., Petrović, V.M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Fluids*, *95*, 309–327.

Pyatt, K., & Sims, R. (2012). Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance and access. *Journal of Science Education Technology*, *21*, 133–147. doi:10.1007/s10956-011-9291-6

Scheckler, R.K. (2003). Virtual labs: A substitute for traditional labs? *International Journal of Developmental Biology*, *47*, 231–236.

Wood, W.B. (2009). Innovations in teaching undergraduate biology and why we need them. *Annual Review of Cell and Developmental Biology*, *25*, 93–112. doi:10.1146/annurev.cellbio.24.110707.175306