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Online laboratory simulations as a pedagogy to reduce anxiety and build confidence for student success

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Abstract

The pivot to blended learning in the post-COVID-19 higher education environment has led to the increased adoption of virtual online laboratories as a mechanism for ensuring that students attain learning outcomes. The fostering of knowledge acquisition and simulation of the practical skills required for laboratory-based disciplines is well established. In this study, we used grounded theory with students as partners to co-create interviews and surveys. The aim of the surveys and interviews was to capture the student experiences and perceptions of the use of virtual online simulations in their studies. A cohort of over 1000 students use virtual online simulations in their programme of study. Of this cohort, approximately 150 students who use the simulations to support practical skills-based aspects of their module assessments were invited to undertake interviews and questionnaires. The online virtual simulations of key scientific techniques were embedded in the virtual learning environment. A common theme that arose through surveys and coding of interview transcripts was that students used virtual simulation as a way of regulating the anxiety they felt towards face-to-face laboratory teaching. Whilst knowledge and skill acquisition are the major focus of university assessment, the self-regulation of anxiety felt by students is a major predictor of success, and this key finding is an under-studied and under-appreciated aspect of the use of virtual online simulations. Virtual online simulations offer a solution to both of these paradigms. They may be sought out by students who see the need to enhance their self-efficacy, and this may go some way to reducing awarding gaps and supporting widening participation in the university student body.

Introduction

Following the COVID-19 pandemic, educational institutions have responded with the further development and widespread adoption of hybrid delivery. In a hybrid learning curriculum, the learning environment consists of both online content and face-to-face teaching. Much of the online content either supports or replaces some face-to-face delivery, and delivery can be synchronous, in the case of streamed lectures, or asynchronous with materials that are accessible at any time through the Virtual Learning Environment (VLE). One of the key advantages of hybrid education is its flexibility and accessibility. Online components of hybrid courses allow students to access course materials and participate in learning activities at their own pace and convenience (Lomellini et al., 2022). The online component of the educational resources enhances the learning experience and provides students with opportunities to engage with course content in a more interactive and immersive manner (Wismer et al., 2021). Hybrid education also offers increased flexibility for both students and instructors in terms of when and where the course is delivered. Instructors can utilise a variety of instructional strategies, such as online lectures, digital simulations, discussion forums, and multimedia presentations, to engage students and facilitate active learning of the curricula (García-Castejón et al., 2021). The use of online platforms and tools facilitates the continuation of teaching and learning activities, ensuring that students can access educational resources and engage in meaningful learning experiences when not in face-to-face activities (Lomellini et al., 2022).

In STEM subjects and particularly in the bioscience disciplines, virtual online laboratories have been used to teach laboratory techniques with significant market penetration and increased popularity in the post-COVID-19 pandemic educational environment (Senapati, 2022; Venter, 2020; Wismer et al., 2021). Labster is one such prominent virtual laboratory that has been widely utilised and it consists of a suite of gamified online simulations of laboratory techniques, procedures, and skills (Makransky et al., 2019). One of the key benefits of digital simulations is that they provide a flexible and accessible learning environment that allows students to engage independently in a self-managed way (Lateef, 2010). In providing simulations as one strategy to support hybrid learning, the students gain the opportunity to access and perform experiments in online virtual laboratories without having to be present on the university campus; students can enhance their understanding of complex scientific concepts and procedures and gain core scientific skills (Hamadani & Wirpsza, 2018). One of the key advantages of virtual online simulations is their ability to connect theory with practice, which bridges the gap between classroom learning and real-world applications (de Vries & May, 2019; Dyrberg et al., 2017). Over and above the simulation of the scientific technique, the Labster platform provides students with a scientific context as well as guidance and support, mini MCQ tests with prompts to theory content, which facilitates their inquiry-based learning (Makransky et al., 2020). The incorporation of MCQ assessments as gatekeepers to simulation progression, coupled with instant feedback, ensures student engagement, and allows them to monitor their progress and identify areas for improvement (Makransky et al., 2020). The use of Labster simulations in hybrid delivery improves student learning outcomes and motivation when compared to traditional lecture-style instruction (Tsirulnikov et al., 2023). Engagement in Labster simulations resulted in higher levels of motivation, self-efficacy, and learning outcomes (Tsirulnikov et al., 2023). The ability to demonstrate laboratory training and the ability to operate in a laboratory-based environment is central to the external validation of many practice-based degrees, such as the role of biomedical scientists in the UK. The Institute for BioMedical Sciences (IBMS) UK provides IBMS accreditation, which covers academic and practical skills and laboratory experience which are required to meet the Health and Care Profession Council (HCPC) standards of proficiency for biomedical scientists and allows those with the accredited qualifications to qualify for laboratory-based roles within the National Health Service (NHS) UK laboratory services. With accreditation of proficiency-based training, it is critical that hybrid delivery has support for proficiency-based training over and above face-to-face sessions. To this end, Labster has also been found to be effective in practical-oriented education, such as where virtual Labster laboratory simulations have been shown to aid in motivation, study intensity, and learning among laboratory technician students (de Vries & May, 2019). The use of simulation in hybrid delivery has enabled students to connect practical laboratory procedures and instrument techniques with theoretical knowledge whilst enhancing the student technicians' understanding of molecular processes (de Vries & May, 2019). Simulations have also proven effective in the education in the wider biopharma industry (Wismer et al., 2021).

One of the advantages of using digital simulations, such as in science education, is the potential to increase access and inclusion for students in the sciences (Lavendier et al., 2022). Accessible technology can be used to provide students with disabilities or campus access issues a more equitable learning experience by enhancing the online offering and thereby increasing their engagement with the hybrid mode of delivery (Lomellini et al., 2022). Education conference presentations have shown an additional benefit of using online simulations in the ability to reduce student anxiety (Damo et al., 2020). Studies showed a theme of increased confidence in face-to-face laboratory sessions, and students viewed virtual laboratories as more approachable and mastered the underlying content better than in purely face-to-face laboratories (Dyrberg et al., 2017; Gao et al., 2020). Online simulation providers seek to support diverse learners by respecting differences in socioeconomic status, culture, ethnicity, gender, and sexuality (Lavendier et al., 2022). The majority of studies of educational simulations relate to medical and clinical scenarios including nursing (Shin et al., 2019) and medicine (McCoy et al., 2016). Whilst the use of laboratory simulations in the biosciences and sport disciplines has not been a focus, the pivot to online learning has increased focus on the use of virtual laboratories either as a replacement for face-to-face sessions or as a support of them. We sought, in this retrospective study, to capture the experiences and perceptions of a large cohort of over 1,000 bioscience, biomedical scientist and sport students accessing online virtual laboratory simulations.

In this study, we used Phenomenological Grounded Theory (Noble & Mitchell, 2016), in which we explored the experiences of students that had used online virtual simulations of laboratory procedures, such as Labster, in their learning journey. We sought to explore the meaning students attach to their experience of support for practical science delivered through simulations of key scientific techniques (Ortiz et al., 2016; Tsirulnikov et al., 2023; Wismer et al., 2021). The principles of Grounded Theory were used to construct in-depth interviews with participants in which we gathered detailed data about their experiences. The interviews were semi-structured, allowing for flexibility to further explore interviewee perspectives (Truter et al., 2021). Interviews were co-constructed with student interns who had previous experience of using digital simulations to support their learning (Figure 1). The data collected from these interviews were analysed using a systematic approach to develop coding, categorise responses, and identify themes (Deterding & Waters, 2021).

The qualitative interview process was combined with a quantitative survey, again co-created with student interns. This provided a mixed methods research approach that used both qualitative and quantitative data to integrate findings and provide a more complete picture (Johnson & Onwuegbuzie, 2004).

Methods

Grounded Theory was used to undertake an iterative project design (Noble & Mitchell, 2016). A two-stage process of study design was undertaken. In the first stage, a student studying biomedical sciences with experience in using digital simulations was interviewed in an online educator forum about their personal experiences of Labster (*Times Higher Educational Supplement*, 2021). In the second stage, the outputs of this presentation and subsequent interviews with this student were used to form concepts and ideas for questions for interviews and quantitative Likert-style surveys. A focus group of two academic staff, who use Labster simulations in their practice, and two student interns, with experience in using the simulations in their studies, were asked to develop interview questions that would explore individual student narratives. The focus groups developed interview questions which focused on gathering rich participant-driven data and therefore were semi-structured to allow exploration of individual narratives. Additionally, Likert-style questions were constructed that developed the themes of the semi-structured interview questions and allowed some quantitative data on these themes to be surveyed in the interviewed students. The questions were grouped into categories, relationships identified, and data was collected in a round of interviews and surveys undertaken by two student intern researchers. The questionnaires were constructed and delivered through the JISC online survey tool (JISC, 2023). Sampling strategy relied on convenience-based sampling, with recruitment emails sent to the cohorts of two modules with a total of approximately one hundred and fifty students out of the total cohort of over one thousand students who had had access to online digital simulations. Recruitment was focused on these two modules from biosciences and sports and these modules were targeted as they used the digital simulations to support assessments in the module and therefore had good engagement in the student cohorts. Approximately 8% of these student cohorts came forward and consented to be part of the study with 12 participants from sports and bioscience disciplines completing the survey. Of these survey participants, nine participants provided recorded interviews (Figure 1) that used the semi-structured interview questions. Semi-structured interviews were recorded digitally using a Philips SmartMeeting recording device and transcribed using Sembly.ai transcription artificial intelligence software; a solution designed for capturing voice-to-text in business meetings. Prior to coding of content, transcriptions were parsed for accuracy and edited before use in further analysis.

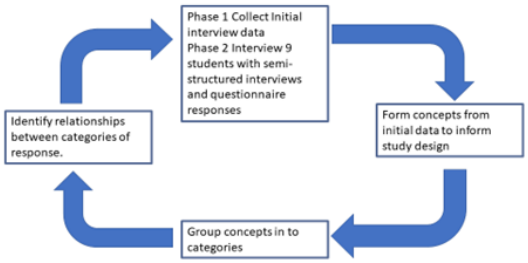

Figure 1: Flow diagram providing a visualisation of the development of the Grounded Theory methodological process.

An initial interview with a student presenter was used to inform focus groups with student interns and academic staff as co-researchers, during which questionnaires and semi-structured interview questions were constructed following the development of concepts and grouping of categories. Interviews were performed and transcripts were then processed and further coded by researchers producing a theoretical framework that explained the data.

All participants were provided with a participant information sheet and consent form on which they could provide consent to participate. Participants were assigned a randomised identifier using the CANDIDATE ID randomiser, available at https://frode-sandnes.github.io/CANDIDATE/ (Sandnes, 2021). This ensured anonymity of interview transcript files used in coding and surveys. No incentive was offered to participants in the survey or interview, nor was it linked to any taught session or assessment in order to reduce response biases. Once surveys were completed, respondents could not edit their results, but they could withdraw their consent, and this was explained to each participant. Students could unenroll from their study at any point, and the randomised identifier used was removed and their records destroyed in obeyance of General Data Protection Regulation (GDPR) UK regulations.

This research is "co-researching and co-inquiring", following Healey et al.'s (2016) conceptual framework, where there is an overlap between subject-based research and scholarship of learning and teaching. Working in partnership with

students is one of the two principles of good practice in Scholarship of Teaching and Learning (SOTL) (Fanghanel et al., 2016). We used it as a pedagogical framework in which we sought to foster authentic engagement of students in collaboration and transformative learning experiences. Northumbria University Research Ethics Committee granted ethical approval for the project, semi-structured interviews, and survey.

Findings and analysis

The initial student interview revealed challenges around practical attendance and anxiety; therefore, the semi-structured interviews and Likert-style questionnaires of the interviewees investigated this topic further.

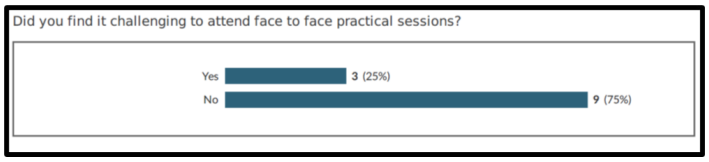

Figure 2: Question on finding attendance challenging with a quarter of student interviewees responding "yes".

In an additional companion question, "If you selected Yes, please specify?" the reasons given were, Response 1 "People sometimes cannot make it on time…we cannot enter the lab and we miss the entire practical…", Response 2 "Social anxiety", Response 3 "COVID".

The transcription and coding of the semi-structured interviews showed that one of the key reasons given for using the simulations was to reduce anxiety surrounding the practical sessions, which was backed by the questionnaire responses. A quarter of interviewees answered yes to finding laboratory attendance challenging (Figure 2) and the interviews generated narrative responses such as:

> And I think it's just a little bit scary to work with people to get stuff done, because like, I feel like if I make a mistake, then that affects their work as well.

The coding of interviews showed anxiety around their ability to perform in the lab. The simulations can be used to gain confidence before laboratory sessions as a pre-laboratory preparation activity. Indeed, when asked, "What did you use Labster for?" in the questionnaire, the most common response from the interviewees was a pre-practical session activity (Figure 3). This was further confirmed as a common theme in the interviews with quotes such as:

> …using them before the practical…I use them mainly as preparation to ease off that anxiety and to gain more confidence on what to expect before practical sessions.

Illustrating that the use of simulations as preparation is a way for students to self-manage their anxiety, illustrated by the quote:

> Yes, I felt anxious during my first lab session so yes, after using Labster it gave me that confidence.

Again, interviewee questionnaire responses confirmed the interview codings with the management of anxiety as a motivation, with common answers being "To gain confidence" and "To reduce anxiety about practical sessions". The outputs from interview coding and interviewee questionnaire align and it would appear the simulations enabled students to self-regulate their emotional response to practical sessions which they may view as stressful. Whilst definitive reasons for student anxiety were not given, quotes connected anxiety to fear of not having the expected knowledge required to perform well in a face-to-face laboratory.

> I use them mainly as preparation to ease off that anxiety and to gain more confidence on what to expect before practical sessions.

> Yes, I felt anxious during my first lab session so yes, after using Labster it gave me that confidence.

> It was something that I really needed to use to be able to pass my degree and to be able to understand what we were supposed to be doing in the lab…

Survey responses show a number of reasons for wanting to use virtual simulations before laboratory sessions: The majority of interviewees used the simulations as pre-practical session preparation, whilst other interviewees viewed it as an alternative to attending practical sessions (Figure 3), which may support students who find attendance challenging. This was illustrated by a written comment on the interviewee questionnaire (Figure 2):

> People sometimes cannot make it on time…we cannot enter the lab and we miss the entire practical.

Laboratory sessions, where students have to attend a safety brief before commencing work, require timekeeping that some students may find more challenging and may act to exclude them from a learning opportunity; these students are more likely to be from widening participation backgrounds (Pickering, 2021).

Another common theme from the interviews was that students saw the simulations as most useful during Years 1 and 2 of their three-year BSc programmes, with the simulations acting as an adjunct to the practical content, as illustrated by the quotes:

> First, I used Labster for practical skills in the first year and microbiology and immunology… principles of cellular and biomolecular analysis in the second year and sometimes cellular pathology and transfusion science…

> I suppose if you can't do it, it would be an alternative, but I would say it's more of an additional… (to practical laboratory sessions).

In addition to the use of simulations to support self-regulation of anxiety and confidence, the students also use the simulations for knowledge acquisition with half or more than half of students selecting "Revision" and "To gain basic knowledge on the subject" respectively in the interviewee questionnaire (Figure 3). Coding of the semi-structured interviews revealed a common coding of response was around "Supporting Learning and Filling Knowledge Gaps" with many interviews producing quotes that support the coding.

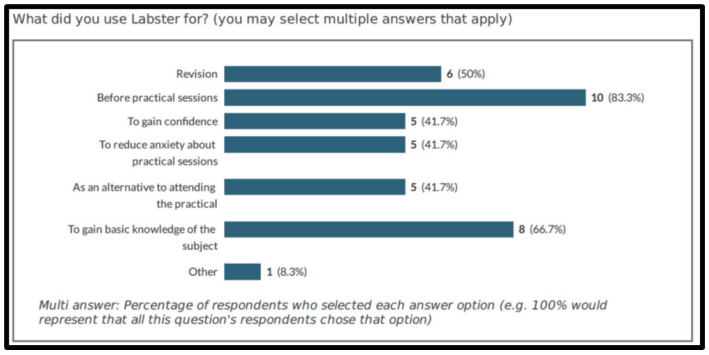

Figure 3: Question "What did you use Labster for?" allowing multiple-response selection by each participant, showing a range of uses for student learning.

Despite the use of simulation being seen as a positive the majority of students were either neutral or negative about the use of imbedded MCQ questions for providing summative marks in the assessment of learning outcomes; with half disagreeing or strongly disagreeing with use in assessment and a total of 91.7% of the interviewees disagreeing or being neutral to use as summative assessment (Figure 4).

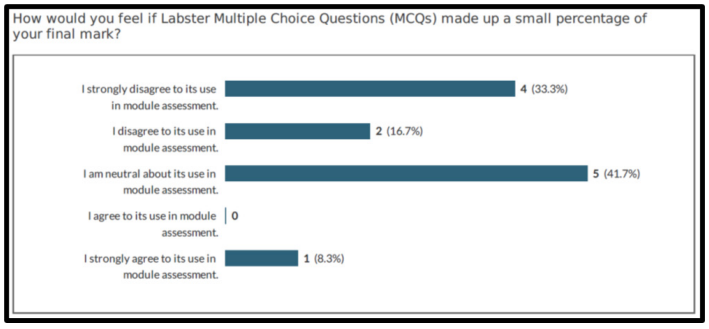

Figure 4: Question on using as a component of summative assessment. With most responses neutral or negative (Total 91.7%).

Discussion and conclusions

The use of Virtual online laboratory simulations in STEM subjects has been well established (Hamadani & Wirpsza, 2018; Makransky et al., 2016; Tripepi, 2022; Wismer et al., 2021; Yap et al., 2021), however, the motivations of student users is less well understood.

From our analysis, a theme on the use of simulations as a means by which students self-regulate their anxiety over attendance of face-to-face laboratory sessions has been developed. In the post-COVID-19 pandemic educational environment, students who have experienced disruption to their university or school studies seek to gain confidence in science topics through knowledge acquisition using the gamified simulations of practical applications and theoretical underpinnings. Student anxiety around face to face laboratory work and their use of simulations to self-regulate the anxiety (Alkan & Erdem, 2013; Damo et al., 2020) is an area of study that would benefit from further development (Logothetis & Flowers, 2020).

Academic tutors often concentrate on the achievement of learning outcomes and assessment performance as a way of measuring success of both the course curriculum and students' knowledge and skills acquisition. Virtual Laboratory simulations have an established pedagogy of successfully fostering knowledge and skills attainments (Makransky et al., 2019; Makransky & Petersen, 2019; Tripepi, 2022; Tsirulnikov et al., 2023). Concerns about the use of online only science courses focus on the applicability of skills for laboratory work.

> The question remains, are students who are exclusively enrolled in online science courses equipped with the cognitive ability to operate laboratory equipment within a physical laboratory? (Rivera, 2016)

However, in this study, using grounded theory with students as partners in the co-construction of questions for questionnaires and interviews has led to a focus not on assessment performance and learning outcome attainment but on the use of virtual laboratory simulations as a way to control anxiety and build self-efficacy. The students who were interviewed mainly used the virtual online laboratory simulations as a preparation for laboratory sessions and as a method for enhancing their knowledge and reducing their anxiety. Laboratory anxiety in scientific disciplines has been reported previously in chemistry laboratory sessions (Galloway et al., 2016), nursing laboratory simulations (Miller & Sawatzky, 2017) and ethnically marginalised students have been shown to have a higher baseline anxiety in laboratory sessions (Soto et al., 2012). With the pivot to blended learning, online virtual laboratory sessions may become a tool that students seek out to address underlying anxiety and enhance their confidence through knowledge acquisition. Whilst anxiety can have detrimental effects on student performance, self-regulation and self-efficacy is one of the main factors that predict success (Duraku & Hoxha, 2018). It may be that our post-COVID-19 blended learning cohorts of students seek out Virtual Laboratory simulations as a way of achieving success. This study shows that the use of virtual online simulations including Labster can be a valuable resource for students allowing them to gain key laboratory skills. Student narratives highlight caution against the growing paradigm of using these simulations for assessment with students on large bioscience and sports cohorts preferring to use them to build confidence and self-efficacy.

Of the students consenting to be interviewed, eight were female and one was male. This somewhat reflected the gender biases of the two courses under study, with sport being under-represented for females and biosciences being under-represented for males. Whilst the focus group did not consider gender or student background in the construction

of semi-structured interview questions and the interviewee Likert-style questionnaires study design, it is interesting that most of the interviewees came from ethnically marginalised or widening participation backgrounds. Although this could represent an increased willingness of these students to volunteer in these roles as a means to have a voice and foster a sense of belonging, the data presented show that virtual online lab simulations used in a preparatory manner may have particular value in overcoming barriers to participation and reduce awarding gaps, which is a well-known problem in the biosciences (Cassambai et al., 2022). The role of online digital simulations in creating a more accessible curriculum in widening participation students will be further investigated and we will also seek to support student researchers to think reflexively about their experiences.

We conclude that this study shows that the use of online virtual simulations is a valuable resource for students and supports acquisition of knowledge and lab skills. Online virtual simulations can enhance the success of blended learning in the new post-Covid-19 educational environment but there needs to be "*a pedagogy that is student-centred… capitalises on the strengths of both synchronous and asynchronous learning.*" (Zhao & Watterston, 2021). Only by considering the students' motivations for the use of online virtual simulations can we appreciate the value they place in them and properly utilise them for a more inclusive and supportive curriculum.

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