Digital Labs as a Complement to Practical Laboratory Training for Bachelor and Master Biomedicine Students

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Abstract
Digital laboratories and simulations have been employed as a teaching method for decades. Their main purpose was to complement theoretical teaching and practical laboratory training. Recent studies have also shown that digital laboratories could enhance students' learning through increasing intrinsic motivation and self-efficacy. In this study, we examined the student perception of using digital laboratories in 13 courses within Biomedicine/Life Science at two different universities, University of Turku and Karolinska Institutet. Using two different sets of survey questionnaires, we collected students' responses and comments students after the end of each course. Students were generally positive to the use of digital laboratories to complement their study. They reported they experienced a moderate increase in motivation and interests to the course content. The digital laboratories could, to some extent, help them integrate theory and practice, and prepare for the real-life laboratory sessions. These findings helped university teachers to gain insight on course design when incorporating digital laboratories in university courses. In this study, we also found that digital laboratories, at this present setting, could not support the teamwork and interactions between students that took place in the real-life laboratory sessions. Since a large amount of data was collected in digital laboratory modules, learning analytics would in the future help to identify the difficult concepts that would require follow-up in other teaching and learning activities. Learning analytics would also provide valuable insight for an informed decision when choosing appropriate education tools for the future generation.

Keywords
Digital Laboratories, simulations, student motivation, science, technology, engineering, mathematics (STEM) education, higher education

1. Introduction

Long before the COVID pandemic, the idea of using simulations and digital laboratories to complement physical laboratories had already been brought forward [1]. The main objective was to provide training of novel laboratory techniques to students despite the concern of cost, time, and safety issues. Throughout the last decade, several studies had shown that immersive digital laboratories/ simulations could enhance students' intrinsic motivation, knowledge, and self-efficacy [2]–[4]. During the COVID-19 pandemic, virtual lab simulations also were used to replace physical

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laboratories or staff training as an effective supplement [5]. Recently, a meta-analysis showed only a medium effect size for the use of virtual laboratory activities to enhance student achievement [6].

In this study, we examined the student perception of using digital laboratories as learning activities in several university courses at two different universities, University of Turku and Karolinska Institutet.

2. Background

2.1. Using digital labs to teach STEM subjects in higher education

Simulations have been employed as a teaching method in higher education for decades. Different types of simulations have been used, for example manikins, standardized patients, role playing, case scenario and digitalized surgery. Simulations have also been used in higher education to mimic real-life laboratory teaching in science, technology, engineering, mathematics (STEM). The purpose of using simulations in STEM education is to prepare students for physical laboratories in safe environments without any time or cost limits [7]. For example, in developing countries, there is a lack of laboratories including reagents, apparatus and expertise for teaching science. However, if ICT infrastructure is at sufficient level, virtual laboratories can effectively replace the need of real laboratories in developing countries. A study by Manyilizu [8] showed that virtual laboratory is a useful tool to learn chemistry in Tanzanian secondary schools. However, the best learning outcomes were achieved when virtual laboratories preceded practical experiments. In international study programmes, students often come from different countries, where they have had unequal possibilities to study in well-equipped laboratories, and their laboratory skills vary a lot. "The Gap problem" defined by Nowacyzk et al [9]), means "A situation where the information, the understanding and the skills that students have are not what is needed for performing laboratory assignments". Virtual laboratories may provide a solution for this problem serving as "bridge-studies" between theory and laboratory sessions. In biomedicine, virtual reality –based teaching, such as virtual laboratories, have also been used to fulfill the 3R (refinement, reduction, and replacement) principle to protect animals. Comparing real and virtual laboratories for pharmacy teaching, Schneider and coworkers [10] indicated that there is no significant difference in learning outcomes between these two teaching methods, although students found real laboratories more interesting. Furthermore, participating in teaching and even in developing of virtual laboratories, have been suggested to provide a great opportunity for doctoral students to gain teaching experience and to place theory into practice [11].

2.2. Digital laboratory/Simulation software Labster

While digital laboratories and simulations used in higher education could be developed in-house to accommodate specific course contents and situations, according to the unpublished survey data within our consortium, many higher education institutes (HEIs) have chosen to purchase ready-made products, especially during the COVID pandemic.

There were several virtual lab simulations and similar resources available before the COVID pandemic and some with no extra cost for the users like the HHMI resources (https://www.biointeractive.org/classroom-resources/immunology-virtual-lab and https://www.biointeractive.org/classroom-resources/transgenic-fly-virtual-lab) Also demonstration videos and related resources, like Journal of Visualised Experiments, was available. In this study, the simulation software Labster was chosen to be the virtual lab platform because of the immersive virtual reality environment, the storytelling of cases and the documented benefit for students' intrinsic motivation, knowledge, and self-efficacy [2]–[4].

2.3. “Do not replace our practical course lab”

Labster simulation modules were first tested on a group of international biomedicine master students at Karolinska Institutet in 2016 as a pedagogic development project with the objectives of (1) diversifying the learning of advanced molecular techniques and (2) promoting integration of theoretical biomedical knowledge with that of practical techniques. In the spring semester 2017, master students were recruited to form a focus group to evaluate how digital lab simulations promoted student learning. The response was generally positive. The focus group highlighted the main benefit as the broad range of methods, including the exposure to advanced instrumentation and lengthy, complex experiments. The focus group also suggested which digital lab simulation modules would fit best into specific courses in the programme. Then in spring 2019, another focus group was formed comprising students from the second year of the Bachelor’s Programme in Biomedicine, to examine the relevance of simulation modules in the Bachelor programme. The general response was more positive than that of the Master’s students. This second focus group also matched courses to simulation modules. Only a handful of courses could clearly benefit from including simulation modules. Overall, this method of using student focus groups to help identify appropriate simulation modules for certain courses had been well-received by both students and faculty. For the faculty, it gave them a sense of confidence in adding extra assignments to their courses. For the prospective students, the fact that the simulation modules were reviewed and selected by their senior peers helped to reassure them that the additional assignments were relevant and worthwhile. The strongest comment was that digital lab could not replace the real-life lab. (Find open answer response)

3. Methods

3.1. Courses in this pilot study

For this pilot study, 10 courses in the field of Biomedicine from University of Turku (UTU) and three courses from Karolinska Institutet (KI) were included.

Courses from the University of Turku were *Medical Biochemistry, Neurobiology, Cell and Molecular Biology and Cancer Biology* within the Bachelor’s Programme in Biomedicine, *Experimental Pharmacology and Methods in Experimental Pharmacology* within the Master´s Degree Programme in Biomedical Sciences, *Methods in Cell Biology, Methods in Molecular Biology, Methods in Protein Purification and Analysis, and Laboratory Medicine* within the Degree Programme in Medicine.

Courses from the Karolinska Institutet were *Genetics, Genomics and Functional Genomics*, *Cell-, Stem Cell and Developmental Biology* within the Bachelor’s Programme in Biomedicine, and *Frontiers in Translational Medicine* within the Master’s Programme in Molecular Techniques in Life Science.

At UTU, the Bachelor´s Programme in Biomedicine and Degree Programme in Medicine were national and Master´s Degree Programme in Biomedicine was international. The courses at KI were in global study programmes meaning students attending the courses were from an international background, and English was the medium of instruction (the course language). These courses received support to pilot digital lab (Labster simulations) by the respective degree programmes, The course leadership chose which simulations and how simulations were presented/used to their students independently.

Textbox: List of courses in this pilot study

Courses at the University of Turku

Bachelor’s Programme in Biomedicine

- *Medical Biochemistry*
- *Neurobiology*
- *Cell and Molecular Biology*
- *Cancer Biology*

Master´s Degree Programme in Biomedical Sciences • *Experimental Pharmacology* • *Methods in Experimental Pharmacology* • Degree Programme in Medicine. • *Methods in Cell Biology* • *Methods in Molecular Biology* • *Methods in Protein Purification and Analysis* • *Laboratory Medicine*
Courses at Karolinska Institutet
Bachelor's Programme in Biomedicine • *Genetics, Genomics and Functional Genomics* • *Cell-, Stem Cell and Developmental Biology* Master's Programme in Molecular Techniques in Life Science • *Frontiers in Translational Medicine*

3.2. Use of Labster in the courses

Students were asked to complete Labster simulations (virtual laboratories) in different ways in different courses. Although not optimal, simulations were used to replace in-person practical labs during COVID lockdowns and, in very rare occasions, absence. Simulations were mostly used as standalone assignments prior to the learning activities, such as lectures and laboratory sessions. On some occasions, follow-up discussion seminars (in-person or digital) were held, and follow-up written assignments were given to students. On some occasions, simulations were given as revision assignments. In some instances, Labster was used as an exercise to be performed during in-person laboratories, for example, during an experimental incubation. In some courses, the performance of Labster simulations was voluntary, but mostly they were mandatory tasks in the course.

3.3. Evaluation questions

For this study, two sets of survey questionnaires were developed to investigate student perceptions of virtual laboratories. The questionnaires included both closed and open-ended questions on various aspects of the students' experiences. **Error! Reference source not found.** shows the questions in these two sets of survey questionnaires.

The first set of survey questions (Set A in Table 1) was focused more on course design while the second set (Set B in Table 1) was more focused on students' experience and learning. The second set of questions in the survey questionnaire (Set B in Table 2 Table 1) was selected from the study by Dyrberg [12] and further developed to fit this pilot study. These questions were validated in a small group of students to ensure that questions were appropriately formulated and correctly understood.

These survey questionnaires were sent to all enrolled students after the end of each course. Students chose actively and voluntarily to answer these questions anonymously. Students were informed that the use of the collected data was for course development and research purposes.

Table 1
Questions used in the two sets of course survey questionnaire in this study

Set	Question text	Answer options/Scale
A	1. Do you think that virtual laboratory simulation is a reasonable way to study biomedicine?	5-point Likert scale + open answer
	2. Would you prefer to perform virtual laboratory simulations at your own time alone or at classroom with other students and teacher?	o At my own tine o Together o It doesn´t matter
	3. Would Labster simulation work better...	o Before the lecture (to orientate to the subject) o After the lecture (to rehearse the subject)
	4. Did the Labster simulation work technically?	o Yes/No o If not, describe the problems
	5. Would you like to have more...	o Theory quizzes o Practical lab work o Animations o Everything was well balanced
	6. Any other comments?	Open answer
B	1. Labster/Digital lab increased my interest towards the course content.	5-point Likert scale + open answer
	2. Labster/Digital lab increased my understanding of the course content.	5-point Likert scale + open answer
	3. Visualising in Labster/digital lab increased my ability to integrate theory and practice.	5-point Likert scale + open answer
	4. Labster/Digital lab prepared me for the laboratory sessions.	5-point Likert scale + open anwer
	5. Has your learning benefitted from Labster/digital lab? Please explain.	Open answer
	6. Did you have any technical problems with Labster/digital lab?	Yes/No. If yes, describe the problems

4. Results

4.1. Response rates

Students from different academic years were given different sets of questionnaires to answer. From UTU, 13 out of 24 enrolled students (54%) during spring 2021 answered the questionnaire set A, and 51 out of 112 enrolled students (46%) during spring 2022, autumn 2022 and spring 2023 submitted their answers to the questionnaire set B. For KI, 50 out of 78 enrolled students (64%) answered questionnaire set A during the autumn term 2021 and 76 out of 135 enrolled students (56%) during 2022 (including the spring term and the autumn term) submitted their answers for questionnaire set B.

4.2. Student preferences on the use of digital labs

In the survey questionnaire set A, we examined students' preferences regarding the best format for incorporating digital labs into university courses. For Q1 "Do you think that virtual laboratory simulation is a reasonable way to study biomedicine?", the responses were positive with 62% of the responses from UTU students and 79% of the responses from KI students being of grade 4 or 5 on a 5-point Likert scale (Table 2). The comments emphasized that digital labs were a good complement to other course content (lectures or laboratory sessions) and provided good preparation for real-life laboratory sessions. Here follow some representative open answers:

- *"It is by no means a replacement, but a nice complementary tool to get a bit more familiar."*
- *"It's ok when lack of real lab work. But mostly good as a preparation for labs and to gain knowledge"*
- *"I feel like it gave me some knowledge that was good to have before doing the actual lab in real life, but in my opinion it should not be used as an alternative to real life labs, more as a complement."*
- *"I feel they are very different from the real situations"*

Concerning questions about the students' preferences on when/where to perform the digital labs (Q3), a clear majority (75%) of students at KI preferred to perform the simulation modules in their own time, while students at UTU were split between no clear preference (46%) and in their own time (39%) (Table 2). Taken together, the least popular option, performing the virtual laboratory simulations together with another student, was common for UTU and KI students.

Table 2
Frequency table on selected questions from the survey questionnaire set A

From Questionnaire Set A	UTU (n=112)	KI (n=135)
Q1: Do you think that virtual laboratory simulation is a reasonable way to study biomedicine?		
1 – No, not at all	0%	4%
2	0%	4%
3	38%	12%
4	31%	51%
5 – Absolutely	31%	28%
Q2: Would you prefer to perform virtual laboratory simulations at your own time alone or at classroom with other students and teacher?		
At own time	39%	75%
Together	15%	7%
It doesn't matter	46%	18%

4.3. Student interest and motivation

In the survey questionnaire set B, we examined student perceptions on how digital labs would be beneficial to their studies. As shown in the Figure 1, the majority of students reported that digital labs increased their interest in and their understanding of the course content. On integrating theory and practice as well as preparation for the practical laboratory sessions, students were positive, but not as clear as for the first two statements. There was also slight difference in skewness of the frequency curves, but the general trend was the same with no significant difference (tested by normality test with z-score) between the two universities.

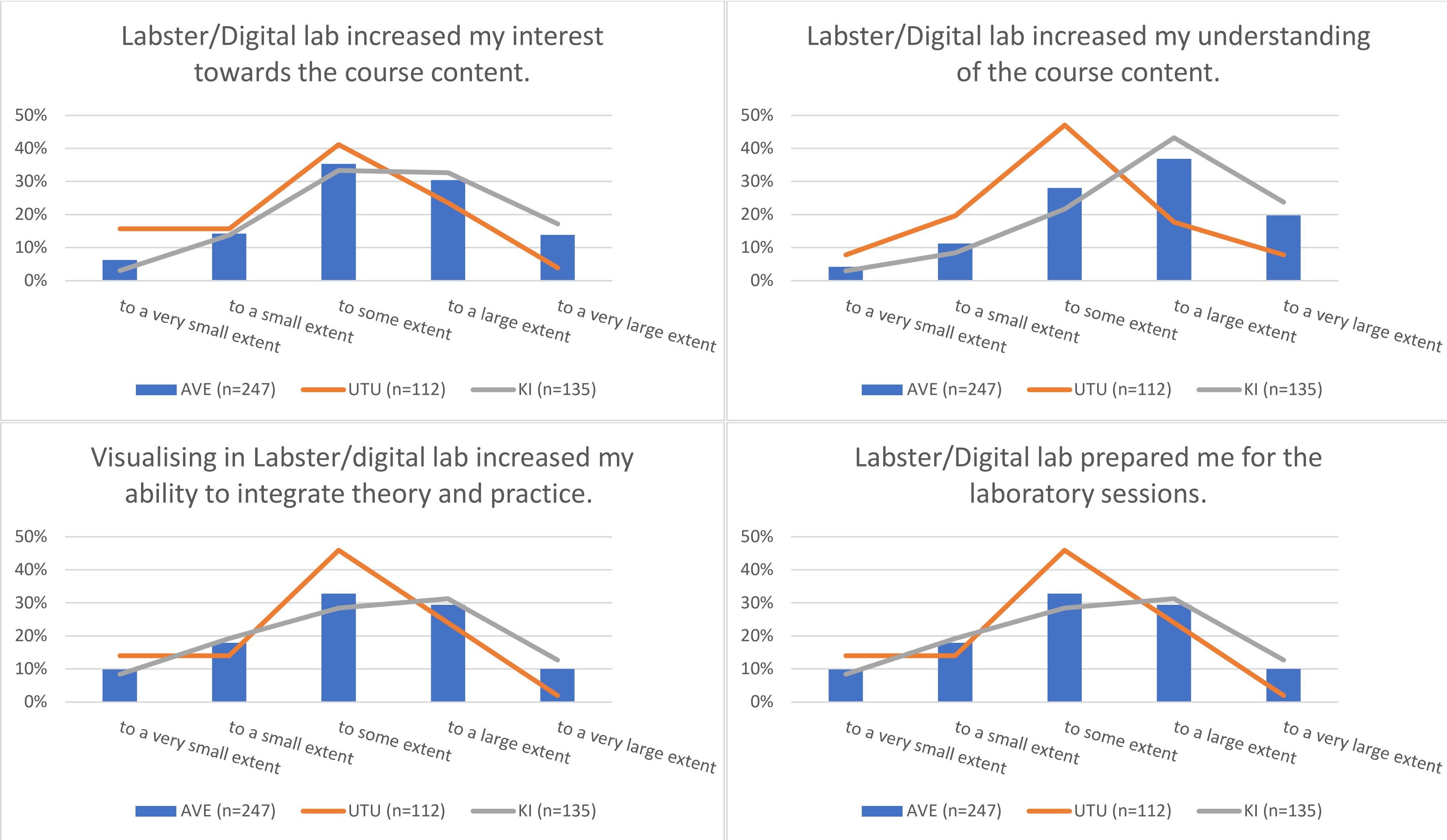

Figure 1: The frequencies of responses from students about their learning experience using digital lab in the respective universities (UTU: University of Turku, KI: Karolinska Institutet, AVE: average from both universities)

There were a few occasions where simulation modules were used as make-up assignments for absence in real-life lab. Students commented that the assignment was more relevant than writing an essay on the topic.

Some representative open answer responses from the impact of digital lab on their interests and understanding were:

- *"The labsters are helpful for understanding the procedures"*
- *"Labster helped with preparing the physical labs – provided some extra, but useful, information"*
- *"All of the labsters were useful and provided either an alternate perspective or a reminder of the theory and integrated it with practice in a useful way."*

Concerning the knowledge acquisition of experimental techniques, the students also noted that digital lab could fill the unmet needs of gaining "experience" in advance techniques like flow cytometry or confocal microscopy when courses could not provide such practical laboratory sessions in real-life.

- *"Labster allows me to do experiments that we didn't have a chance to do in an actual lab."*
- *"It was useful to have some more complex procedures explained. Also, Labster helps much more to understand such things as FACS than watching multiple YouTube videos."*

About the function of preparing students for laboratory session, one response touched upon self-efficacy:

- *"It gave me a better overview of a biological lab and made me less anxious for the actual labs."*

Among the negative comments, it was predominately about the low difficulty level from the Master students:

- *"I personally did not like the Labster simulations. They felt burdensome and more for someone in an earlier point of their science education."*
- *"Could be extremely useful for those with no prior experience."*

5. Discussion

From this pilot study, we examined the student perception of using digital laboratories in 13 courses within Biomedicine/Life Science at two different universities, University of Turku and Karolinska Institutet. Using two different sets of survey questionnaires, we collected students' responses and comments students after the end of each course. Students were generally positive to the use of digital laboratories to complement their study. They reported they experienced a moderate increase in motivation and interests to the course content. The digital laboratories could, to some extent, help them integrate theory and practice, and prepare for the real-life laboratory sessions.

5.1. Limitations

There are a couple of limitations in this study: aggregated course occasions, sample size and only one validated set (Questionnaire set B) of questions.

We chose to aggregate the responses from students from different courses in order to achieve a reasonable sample size for analysis. How the simulation modules interacted with the rest of the course content could vary a lot. The number of simulation modules used and which simulation modules used also varied between courses. These heterogeneity in course design reduced the specificity of the responses to the statements. While only a handful of courses involved in this study had around 50 students enrolled, most courses had 20-30 students attending. The responses from courses with more students might be over-represented while courses with less students would be under-representative despite a higher response rate. Some students might have attended more than one course covered in this pilot study, hence answered the survey more than one time.

Another limitation was that the first survey questionnaire was not validated by testing on a small group of students and some questions could be interpreted differently by different students.

5.2. Insights from students' feedback

From this study, we found that digital laboratories using Labster increased students' self-reported interests, understanding and integration of theory and practice (Figure 1). This was in agreement with previous studies made using the same software but with different modules and in different context [2]–[4]. The self-reported interest showed smaller effect than the increase in understanding and integration. Moreover, for the question on integration of theory and practice, the distribution was wider than the question on understanding. Since different modules were used in different courses, there were multiple underlying factors in the perceived benefit in integration of theory and practice. This could imply that Labster simulation modules in general had a clear benefit for the students' understanding of the subject content.

The distribution was more skewed towards the higher Likert scale (i.e. agreement of the statement to a larger extend) in responses from KI than from UTU (Figure 1). We reflected on the possible reason for this phenomenon. It might be explained by the pre-COVID preparatory work with student focus groups at KI to align simulation modules to courses both on difficulty and content knowledge. The student focus group also performed a "quality control" to identify high quality simulation modules. At KI, there was also prior teaching experience (both success and failures) in implementing the simulation modules before the COVID pandemic. So, when using simulation modules to replace or complement some other learning activities, there was a faster transfer know-how and technical support.

The situation at UTU was different, as Labster was implemented in the courses only after the COVID-19 lockdown. After the pandemic, students were probably enthusiastic to work on-site and were not keen to apply online solutions to their studies. Furthermore, teachers had no previous experience of Labster and perhaps they were not able to choose the most relevant simulations for students. Based on the students´ feedback, the selected simulation modules might have been too easy for some courses at UTU, as student feedback stated:

"There wasn´t that much new or challenging information that would have affected my interest in the course."

Most Labster simulation modules covered the basic scientific knowledge equivalent to the difficulty levels in the high school (grade 10-12) and the early years in the first-cycle education at HEIs. Depending on whether the students would complete an easier simulation module before a more advanced lecture, or vice versa, the students' perception of learning motivation, interests and understanding would be very different.

5.3. Insights on course design – Towards a best practice

Even though the survey questionnaire set A was not validated before we collected responses, there were common preferences from students attending both universities – a clear majority were positive to using digital lab simulations as a teaching/learning activity, and most students prefer to do the simulation assignments at their own pace. It is difficult for students to judge whether the digital lab should be linked to another teaching/learning activity or not. And if linked, whether the digital lab should be performed before or after the teaching/learning activities. These questions are for the course designer to answer.

Labster simulation modules are designed as self-contained learning activities. Certain simulation modules work best as standalone assignments. Many Labster simulation modules could be linked to other teaching/learning activities to enhance students' learning. For example, synchronous activities such as lectures and laboratory sessions, and asynchronous activities such as quizzes, written reports, calculation exercises. For the synchronous activities like lectures, seminars and laboratory sessions, most students found simulations more beneficial before, given that the simulations served as an introduction to the topic or method. There could be occasions when simulation modules could be more appropriate to be performed after the lecture if the virtual laboratory would further the context of the linked activities. One example would be the more complex concepts on human genetics and translational medicine. The simulation modules could consolidate what students learned in a lecture or seminar and applied in the virtual scenario.

From the student focus groups at Karolinska Institutet, apart from the “match-making exercise” grading the relevance of simulation modules in different courses, the student focus group also commented on the format for incorporating digital labs into the courses. With the variety of simulation modules, there was no standard format, but the key was to communicate to the students clearly and timely. By explaining why certain simulation modules were chosen and in which way the linked activities could enhance their knowledge, the students could then understand their progression in learning.

5.4. Future prospective

Digital labs cannot replace real-life laboratory sessions, although they could provide training in advanced methodologies and lengthy experimental procedures. Questions remain as to how we can measure the benefit of learning and the type of learning. Several studies have demonstrated Labster simulation could increase student self-efficacy [2]–[4]. It was interesting that one open answer response mentioned just that. Further studies are needed to further explore which types of tasks could the increase in self-efficacy result in an actual hands-on knowhow in the real-life laboratory session.

From the survey questionnaire set A, only few students liked to perform the virtual laboratory simulations together with other students in both the UTU and KI student groups. Teamwork is an important element in real-life laboratory sessions in the university setting. This further strengthens the statement that virtual laboratory simulations should not replace real-life labs.

Learning analytics (LA) is a multidisciplinary field combining computer science, education science, data mining, statistics, pedagogy and behavioral science [13]. During the last decade, it has been successfully used to improve and optimize education [14]. However, a recent systematic review of using LA in virtual laboratory teaching indicates that the potential of LA to analyse and consequently support learning in virtual laboratories, have still not been largely utilized. Thus, combining LA to virtual laboratory programs is of great interests for the future

While simulation based medical education was regarded as a “a powerful educational intervention when it is used under the right conditions” [16], a recent meta-analysis could only show a medium effect size for the use of virtual laboratory activities on student achievement [6]. Digitalization in practical education could improve students’ learning and offer diversity in learning methods. There is a need now, post-pandemic, to evaluate the impact digital simulations had on students’ learning and perform a cost benefit analysis.

In summary, our pilot study provided useful insight on incorporating digital laboratories in university STEM courses. We also found that digital laboratories could enhance students’ interests and knowledge acquisition. However, at this present setting, there is limited possibility for simulations to support the teamwork and interactions between students that took place in the real-life laboratory sessions. Since a large amount of data was collected in digital laboratory modules, learning analytics could in the future provide valuable insight on how learning took place in the digital environment.

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