Perception of Students in Virtual Laboratories: The Role of Context

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Introduction

In biomedical engineering (BME) education, graduates often face challenges in applying theoretical knowledge to real-world engineering scenarios. Their inability to relate theory to practice is detrimental to the BME workforce readiness [1]. Current BME education research indicates an increasing effort to integrate technology into BME instruction. For example, some studies have reported the use of virtual reality (VR), to facilitate the integration of theoretical knowledge and practical skills in BME education [2]. Efforts to integrate virtual reality (VR) laboratories into engineering education have aimed to provide holistic learning experiences to learners [3]. One of VR's specific potentials lies in its ability to help learners visualize abstract concepts and experiences in close-to-real-life settings, independently from constraints such as limited space, safety concerns, and cost limitations [4-7].

Existing research efforts have focused on advancing the utility of VR laboratory environments for improved learner preparations based on the learners' specific experience or the achieved learning outcomes. Learning outcomes such as test performance [8] and technical skill development [9] have also been assessed to measure the efficacy of VR laboratories with positive results observed. Concerning the learners' experiences, prior studies have focused on learning motivation [10], satisfaction [11], and perceived usefulness, [8, 11] among others. These student-focused factors have been described in the existing literature to play significant roles in the successful implementation of VR laboratories for engineering education settings [12].

However, contextual factors such as physical, social, and instructional environments also play huge roles in the learning process [13, 14]. Hence, instructional design considerations become increasingly vital to ensuring students get optimal learning experiences in instructional VR environments [3]. Understanding the role of contextual aspects extends our knowledge of design requirements for specific content types and difficulty levels. As Lynch and Ghergulescu [15] highlight, there is no one-size-fits-all for VR lab instructional design. Therefore, effective VR laboratory design environments are heavily dependent on our identification and exploration of influencing factors for diverse students' learning experiences.

Studies that explore situations in which learners get multiple exposure to learning in VR environments are needed to better understand the effect of different contextual factors on VR learning. However, most prior VR studies have been carried out in a single laboratory. As such, there is a gap in the literature examining the effects of multiple exposures to VR instruction on learners' perception of VR laboratory learning. The current study explores students' perception of satisfaction, perceived usefulness, and learning effectiveness after participating in multiple VR laboratories in a single course to understand the use of VR laboratories and their influence on the learning experience. We explore differences in student perceptions of these factors and investigate the role context plays in influencing or shaping these perceptions.

Literature Review

VR Labs in BME Education

The review on virtual and augmented reality in biomedical engineering conducted by Taghian et al. [16] emphasized the integration of VR technology into medical education, surgery, and rehabilitation, underscoring its potential to advance the BME field. Additionally, a study by Trumbower and Enderle [1], introduced PC-based virtual instruments that offer cost-effective opportunities for students to gain hands-on experiences, develop measurement skills, and apply engineering theories to medical and biological contexts. These instruments provide flexibility in experimentation while mitigating the need for expensive BME laboratory equipment.

Furthermore, to demonstrate the potential of VR in medical training, Burdea et al. [17] investigated the use of VR-based simulators to enhance training for prostate cancer diagnosis and found that VR-based simulators were useful as a means of improving training in prostate palpation through virtual prostate palpation simulator. Also, Singh et al. [18] study compared the effectiveness of VR videos to traditional 2D videos in fostering immersive experiences for interdisciplinary teams addressing clinical problems. Their study highlighted that VR enhanced collaboration and communication skills among participants, potentially extending virtual immersion to global clinical settings for broader student awareness in BME education. In addition, the study by Wilkerson et al.'s [19] explored the efficacy of VR videos in engaging students and improving their understanding in an undergraduate course. While the study revealed positive impacts on students' quiz scores, concerns were raised regarding video length, content quality, and technical issues related to VR equipment.
Overall, these studies highlight the increasing integration of VR technology into BME education, emphasizing its potential to enhance learning experiences, practical skills, and interdisciplinary collaboration in the field.

Student Factors in VR Laboratory Education

Previous research highlights the high utility value of integrating virtual reality settings into education. For instance, Winkelmann et al.'s study [20] demonstrated that students who conducted experiments in a Second Life virtual laboratory achieved better grades in quizzes and lab reports than those in a real-world laboratory. Finally, virtual labs not only serve as a complementary or alternative approach connecting problem-based learning (PBL) to the real world but also enhance student satisfaction, as shown in the study by Vrellis, Avouris, and Mikropoulos [21]. Their study revealed that students expressed higher satisfaction while performing activities on the reflection of light in Multi-User Virtual Environments (MUVE) compared to real-world scenarios.

Furthermore, Cobb et al.'s study [22] supports the idea of using virtual laboratories before real-world experiments to enhance student preparation and organization, thereby reducing the demand for demonstrator time. The study also revealed that virtual labs effectively facilitated learning gains and were well-received by students, underscoring the potential of virtual environments in education. In our previous study [23], we highlighted learners' positive perceptions of the VR lab's usability, utility value, tool efficacy, and satisfaction. Whether VR laboratories improve learning outcomes depends on a range of factors. Amongst these factors are students' perceptions of satisfaction, learning effectiveness, and utility value [24].

Context in VR Laboratory Environments

Learning does not occur in a vacuum. Rather, it occurs with the confines of multifaceted levels of contexts – thus revealing the complexity of learning in virtual learning environments. In addition to student-related factors, content-related factors like difficulty level and subject context are important considerations for VR laboratories as a form of virtual learning environment for fostering positive learning experiences. Tessmer and Richey [14] define context as "a multi-level body of factors that embed learning and performance." They discuss varied levels of context in their study on contextual analysis for instructional design calling for a more nuanced conception of context that facilitates learning, performance, and motivation. Context viewed through diverse lenses proved to have an influence on successful learning despite its underemphasized position in literature [14].

Context is conceptualized as an interpretative lens for understanding students' activities when engaged in learning [13]. In a study on the role of instructional context for learner engagement in online videos, Seo, et al. [13] investigate context (course period, exam, and rewatch behavior) and observe a positive association between instructional context and video engagement among online students emphasizing its importance in online learning. Similarly, Mutambik, et al. [25] focus on the physical context (school and society) in assessing learners' readiness to use e-learning and reported a direct relationship. They highlight that readiness to use e-learning revolves around learner's subjective experiences within a perceived context.

We situate our definition of context with the learner task perception under learners' factors at the instructional context level [14]. Context in this study refers to the course content and perceived level of difficulty. We postulate that the nature of the course content and the perceived difficulty associated with it by students play a role in how they engage with VR laboratories for learning. We therefore investigate the role of context in learners' perceptions of virtual laboratories for learning towards informing instructional designers and instructors on implementation strategies for specific course contents.

Purpose of the Study

This study investigates the role of context in virtual laboratory design by measuring differences in learners' perceptions of virtual laboratories focused on different concepts. The study builds on our previous study [23] in which we presented preliminary findings of one of 5 different biomedical engineering virtual laboratories integrated into a Tissue Engineering course. Our guiding research questions are*:*

(1) How did learners' perceptions of VR labs vary across lab types?

(2) To what extent did the perceived utility value and tool efficacy of the VR lab modules predict learners' perceived satisfaction with the learning experience across different lab types?

Study Course Context

The Tissue Engineering course where these labs were integrated is an elective course offered for students in Biological and Biochemical Engineering degree programs. The goal of the course is to provide a foundational understanding of the areas of science and engineering involved in the design and development of replacement tissues and organs for the body. The course, although primarily taken by undergraduates in the fourth or fifth year of their degree program, is offered as a split-level undergraduate/graduate-level course.

The course enables students to apply concepts of general sciences (i.e., biology, chemistry) and engineering that they have learned throughout their degree program. The concepts of biology, medicine, and materials science are applied in tissue engineering, where the overarching goal is to develop artificial tissues and organs that can be used to improve medical conditions faced by humans. The course objectives are determined such that by the end of the course, students should: understand the principles behind tissue engineering strategies, understand the integration of biological and engineering concepts to solve medical problems, understand ethical concerns related to biomedical research, and be able to read, comprehend, and critically evaluate research papers, publications, etc., pertaining to tissue engineering.

Selected VR Laboratories

This study administered commercially available desktop VR laboratory modules selected from the suite of simulations produced by Labster. The selected labs were as follows: 1) Cell Culture Basics: Plate, Split and Freeze Human Cells, 2) Fluorescence-activated Cell Sorting (FACS), and 3) CRISPR-Cas Applied to TGF-beta Induced EMT (CRISPR). We present sample images and descriptions from these VR labs in Figure 1. The virtual labs selected for implementation in the course and evaluated for this work were chosen based on their applicability and alignment with the Tissue Engineering course objectives. Specifically, cells are the key building block for tissues of the body, and it is essential to understand how they are grown and maintained outside of the body, as emphasized in the Cell Culture Basics virtual lab. There are also several tools and techniques used to assess cells as they are maintained outside of the body and used in tissue engineering research, such as demonstrated in the FACS virtual lab. Further, additional technological advances have been vital to biomedical and tissue engineering research, such as highlighted in the CRISPR virtual lab.

Study Procedure

The VR labs were incorporated into an existing Tissue Engineering course curriculum. The labs were assigned as take-home activities following the delivery of classroom lectures related to the lab concepts. For example, the Cell Culture Basics lab was the first lab assigned following the delivery of a class lecture focused on cell sources and cell culturing. The lecture focused on the history of cell culture, introduced the equipment and reagents needed for cell culture, and provided an overview of the aseptic technique. Then, in the VR Cell Culture Basics lab, students prepared culture media, passaged cells, and froze cells for long-term storage.

Following the specific classroom lectures, students were given an assignment sheet with login instructions and assignment details for the VR lab. They were also provided with a Virtual Lab Manual developed by Labster for each of the VR labs assigned, which detailed the lab activity and provided additional information on the lab learning objectives and the technique or theory being covered by the lab. While there were Labster-developed quizzes within each of the VR labs, a post-module activity was assigned withto each lab to reinforce the technical topic being addressed (Figure 2). Each student was given free access to the VR laboratories using their institutional login credentials and could access the labs from anywhere using any laptop or desktop computer.

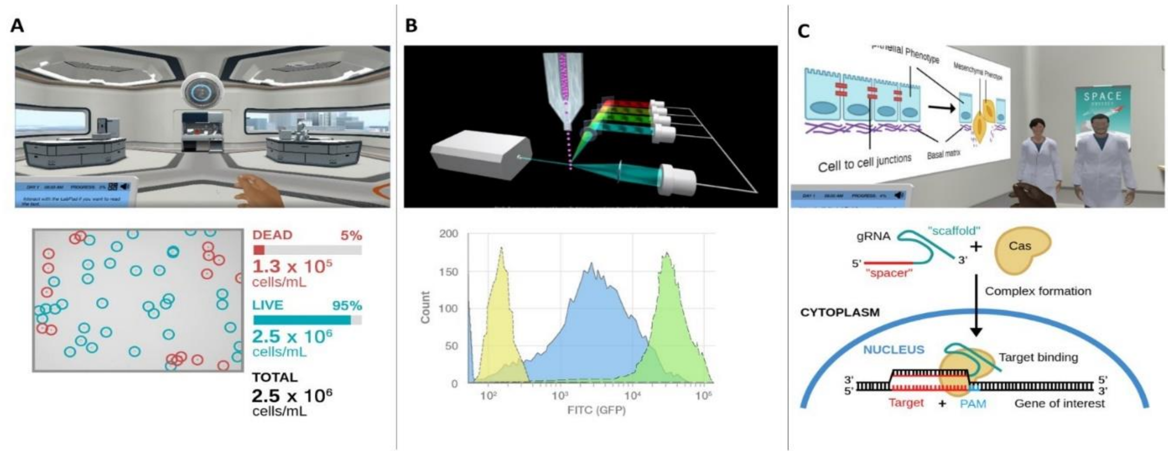

Figure 1. Representative images from the selected VR labs. A) The lab environment from the Cell Culture Basics virtual lab and an example of cell counting data obtained during the lab experiment when using an automated cell counter. B) Schematic of the flow cytometer function in the FACS virtual lab and an example histogram obtained when cells labeled with green fluorescent protein (GFP) were sorted using FACS during the experiment. C) Introduction of the CRISPR virtual lab and schematic demonstrating cell modification using Cas during the virtual lab experiment. Images courtesy of Labster.com.

Module	Pertinent Learning Objectives	Post-Module Assignment
Cell Culture Basics	Describe and perform the key steps when working with mammalian cells in vitro	Cell seeding and counting problem set
Fluorescence-activated Cell Sorting (FACS)	Understand the basics of flow cytometry technique	Research article with questions and critique
CRISPR-Cas Applied to TGF-beta Induced EMT (CRISPR)	Describe the basics of CRISPR-Cas technique and prepare cells for immunostaining	Research articles and questions related to emerging technologies contributing to biomedical advances

Figure 2. Description of pertinent learning objectives and the post-module assignment for each of the VR labs.

Study Participants

Participants in this study were students in the College of Engineering of a public research university in the southeastern U.S. enrolled in a Tissue Engineering course. The data used in this study consists of the responses of 29 students, who consented to be included in the research. A formal IRB (Institutional Review Board) protocol was submitted for the study and approved by the IRB unit (anonymized code) of the institute, and student consent was obtained for their participation in the study.

Participants included 29 students (15 females and 14 males), with the majority being 4th year undergraduates (72%) in biological engineering (45%), biochemical engineering (41%), and other (14%) majors.

Measurements

We administered a 33-item instrument (with four sub-scales), adapted from [26] – perceived usefulness scale, [27] – System Usability Scale (SUS), [28] – satisfaction survey, and [29-31] – Perceived effectiveness scale, to assess the research variables on a quantitative scale. To gather qualitative data, we included a series of open-ended questions in the administered survey. Items were assessed on a 5-point Likert-type scale ranging from 1 to 5 – with 1 being "strongly disagree" and 5 being "strongly agree". The survey was administered online on the Google Forms platform. We focus on three constructs for this research in line with our study objectives and provide operational definitions below.

Tool Efficacy: This is the degree to which learners gauge a learning resource as useful in fostering effective learning outcomes. We measure learners' perception of the ability of the VR laboratories to foster effective learning outcomes in the Tissue Engineering course using the perceived effectiveness survey adopted from [29-31].

Utility Value: This is the degree to which learners view an activity as valuable for their overall learning advancement within and beyond a specific course. We measure learners' perception of the perceived future benefits of VR laboratories for their overall learning, beyond the Tissue Engineering course, using the perceived usefulness survey adopted from [26].

Satisfaction: This is defined as the level of contentment learners experience during a learning activity and in the use of a learning resource. We measure learners' overall sense of satisfaction with the VR laboratories using the satisfaction survey adopted from [28].

Results

In answering our research questions, we present results from our analysis of the quantitative surveys followed by that of the qualitative (open-ended questions) survey for each of the VR laboratories. An example of the open-ended question was "how would you describe the usefulness of the VR lab experience for you and your personal experience?" We use findings from our qualitative analysis to explain our quantitative findings, making interpretations, and drawing insights for instructors and instructional designers on factors that influence positive perceptions of VR laboratories for improved learning experiences.

Prior to conducting statistical analysis for our research questions, we conducted a preliminary analysis on the reliability of sub-scales and correlations among variables, to determine whether our data satisfied assumptions for linear regression for each of the laboratories. In Tables 1-3 below, the Cronbach's alpha ranged between .89 to .94 revealing a high internal reliability of sub-scales. Statistical assumptions for conducting multiple linear regression were met across the three laboratories as a visual inspection of scatter plots revealed a linear relationship between each independent variable and the outcome variable.

We present the descriptive statistics, correlations, and reliability coefficients of the subscales for each of the VR laboratories in Tables 1-3 below.

Table 1: Descriptive Statistics and Correlations among Variables in the Cell Culture VR Lab

Constructs	Tool Efficacy	Utility Value	Satisfaction
Tool Efficacy	1		
Utility Value	.723**	1	
Satisfaction	.706**	.788**	1
M	3.76	3.73	3.81
SD	0.59	0.80	0.65
Skewness	-1.49	-1.02	-1.23
Kurtosis	3.42	1.36	1.82
Cronbach's α	.87	.89	.91

** Correlation is significant at the 0.01 level (2-tailed)

Table 2: Descriptive Statistics and Correlations among Variables in the CRISPR VR Lab

Constructs	Tool Efficacy	Utility Value	Satisfaction
Tool Efficacy	1		
Utility Value	.465**	1	
Satisfaction	.904**	.518**	1
M	3.44	3.67	3.48
SD	0.80	0.96	0.97
Skewness	-1.1	-1.49	-.69
Kurtosis	2.36	2.62	-05
Cronbach's α	.94	.91	.96

** Correlation is significant at the 0.01 level (2-tailed)

Table 3: Descriptive Statistics and Correlations among variables in the FACS VR Lab

Constructs	Tool Efficacy	Utility Value	Satisfaction
Tool Efficacy	1		
Utility Value	.800**	1	
Satisfaction	-.229**	-.062**	1
M	3.65	3.87	3.75
SD	0.75	0.69	0.71
Skewness	-.77	-1.3	-.53
Kurtosis	.94	2.47	-.19
Cronbach's α	.93	.89	.92

** Correlation is significant at the 0.01 level (2-tailed)

Research Question 1*: How did learners' perceptions of the VR labs vary across lab types?*
We carried out a one-way ANOVA as our data met the assumptions upon which the test is based (comparison of two independent groups on a scale variable, normal distribution, and homogeneity of variances). We observed p values greater than .05 for learners' perceptions based on lab type across each of the investigated constructs. This is represented in Table 4**.**

Table 4: Differences in Learners' Perception across Cell Culture, CRISPR, and FACS VR Lab.

	Cell Culture		CRISPR		FACS			
	Mean	S. D	Mean	S. D	Mean	S. D	F	Sig
Tool Efficacy	3.76	0.59	3.44	0.80	3.65	0.75	1.47	0.24
Utility Value	3.73	0.80	3.67	0.96	3.88	0.69	0.48	0.62
Satisfaction	3.81	0.65	3.48	0.97	3.75	0.72	1.43	0.25

We carried out a thematic analysis of our qualitative data adopting Braun and Clarke [32] reflexive TA (Thematic Analysis) approach. Upon data familiarization, we conducted inductive coding in which we generated themes from the data based on learners' perceptions. Below, we report on themes across each of the constructs – tool efficacy, utility value, and satisfaction, highlighting similarities and variations across the three VR laboratories. Following each of our themes' discussion, we will also give examples in the form of direct quotes from the database (in italics).

Tool Efficacy

In analyzing responses on tool efficacy, we generated three major themes with different codes. The themes are learning modality, laboratory technique development, and juxtaposing virtual labs with physical labs. Below, we discuss each of these themes in detail and present direct quotes from the dataset.

Learning Modality

This theme captures perceptions centered around the forms of learning fostered by using the virtual laboratory. It bears similarity to the learning activity theme under satisfaction but places more focus on the mode of learning experienced in the VR labs. Active learning, memorization, information retention, and concept application amongst others appear as recurring codes in this theme. While the VR labs did not offer personalized learning experiences, they catered to individual learners by allowing them to go at their own pace and time. Learners could actively engage with the laboratory environment during their most productive hours and in line with their capabilities without feeling bored or pressured. Across the three labs, learners perceived the virtual labs to be a good complement and reinforcement for classroom lectures as it enabled them to apply concepts learned in class. In this theme, only the FACS lab was perceived to have had difficult concepts that impeded effective learning.

> *"The virtual lab works great as a supporting tool and reinforces information learned in class."*
> *"This virtual lab was useful in helping me learn at my own pace. It gave me options to keep doing genome sequencing or if I was comfortable with it, I could progress to the next step."*
> *"I think the overall concept of this lab was simply hard to grasp."*

Laboratory Technique Development

This theme captures references to technique development within the virtual laboratory. It encapsulates feelings of accomplishment with learned techniques and confidence in the ability to replicate techniques in the VR labs. Learners highlighted the effectiveness of the VR labs in teaching about laboratory practices in a way that enhanced understanding beyond the classroom sessions. They specifically mentioned techniques like cell culturing, machine operations for longer life, cell sorting, and data analysis amongst others. Our analysis also captured feelings of confusion and uncertainty concerning the applicability of techniques in industrial settings. Some learners felt unsure as to transferring techniques they had learned and expressed the need for more practice to build their confidence. Despite most learners perceiving the three virtual labs to have been useful in learning about safety guidelines and techniques, a few perceived the FACS lab to have had confusing techniques that they could not confidently replicate without supervision.

> "*I do know more about lab practices than I otherwise would have."*
> *"It is very good, but I feel like I would not be able to replicate this in the lab without instructions and/or supervision."*

Juxtaposing Virtual Labs with Physical Labs

This theme relates to comparisons learners make between the virtual lab experience and an actual or expected physical laboratory experience. It captures assumptions and expectations learners have about the physical laboratory experience and their reflections on how it bears similarity to the virtual laboratory experience. In their comparisons, learners highlight how the virtual experience could not substitute the physical laboratory experience, emphasizing the need for physical laboratory engagement in developing a well-rounded BME education. Across the three laboratories, learners indicated they had no fear of messing up or making errors during experiments allowing them to focus on learning concepts compared to a physical laboratory. This affordance was expressed as a pitfall if physical laboratory experience were not provided as a follow-up. Additionally, they found the cell culture and CRISPR lab to be effective in offering insight into what a physical lab looks like.

> *"I found this experience to be useful in learning various lab techniques, especially because there was no consequence if I did the wrong thing (i.e., chose the wrong media for the cell culture), as there would be in a real lab. This allowed me to explore without fear of doing something wrong."*
> *"It can give a basic idea of what it is like in a lab setting without going to one in person"*

Utility Value

Our analysis of responses on utility value generated three major themes with different codes. The themes are enhanced understanding and utility of VR labs in relation to physical labs. Below, we discuss each of these themes in detail and present direct quotes from the dataset.

Enhanced Understanding

This theme describes perceptions of learners on the learning opportunities and activities the virtual labs fostered enabling a deeper understanding and engagement with the complex classroom concept applications. The usefulness and beneficial nature of these learning opportunities were reiterated in learners recurring comments on having an enhanced understanding of concepts. The computer analysis and video display of the CRISPR lab were deemed useful while the technique practice for gaining equipment familiarity were majorly highlighted in the Cell Culture and FACS lab as useful. Across the three labs, the ability to apply learned concepts from technique demonstrations, gain clearer perspective of lab due to the visual representations, and view representations of experiments were perceived to be beneficial.

> *"I found it useful how it was life-like, and I could see the true protocol of using CRISPR."*
> *"I feel more familiar with the technique now than what I would have if I had learned this through a lecture."*

Utility of VR Labs in Relation to Physical Labs.

This captures perception of learners in relation to the usefulness of virtual labs as a supplement, replacement, or replication for physical laboratories. Learners opined that the VR labs served as a beneficial supplement for physical laboratory education as they offer a useful form of preparation before transitioning to physical laboratory environments. Across the three labs, learners acknowledged the convenience of virtual labs in terms of location, time, and experiment attempts flexibility while saving cost and working at an individual pace to be a beneficial feature over physical lab. However, the scripted environment of virtual labs which downplays errors and experiment sensitivity was commented on to be a major impediment to their utility in relation to physical labs. This perception resulted in recommendations as to the need to incorporate physical laboratory activities in BME education beyond VR labs.

> *"Although I like the ease of the guided simulation, I think it takes away from true lab experience in making mistakes or making sure you are grabbing the right thing or amount."*
> *"I believe that the virtual experience would be very useful because I was able to choose the best time for me to learn and prepare for the material beforehand."*

Satisfaction

In analyzing responses on satisfaction, we generated two major themes with different codes. The themes are learning space affordability and learning activity. Below, we discuss each of these themes in detail and present direct quotes from the dataset.

Learning Space Affordability

This theme captures the experiences of learners with the affordances of virtual learning spaces that contributed to their overall satisfaction with the virtual lab. Across the three laboratories, learners expressed feelings of safety with less worry about errors while also expressing feelings of frustration and disengagement with the virtual nature of the laboratory environment. While the virtual nature of the labs enabled them to have a space to experiment and fail without consequences thus aiding their learning, it also resulted in disengagement as there was no opportunity for discussions as is obtainable in physical classroom environments. The convenience and self-paced flexibility enjoyed were majorly recurring codes in the cell culture and FACS lab while the comfortability of the learning environment was majorly observed in the cell culture and CRISPR lab.

> *"I found it much more relaxing as there would be very little consequences for any errors I would make."*
> *"The program is intuitive and not difficult to learn, but it does not engage me because all I see is another computer screen, I have to stare at instead of doing "real" work, in school, in person."*

Learning Activity

This describes the forms of learning activities facilitated by the virtual lab that fostered satisfaction. Learners reported increased interest due to the question type and clarity of information provided in the virtual laboratory, creating a desire to engage more and learn concepts. The guided activities in terms of step-by-step procedure for lab protocols and safety techniques increased learners' satisfaction with the VR labs as they felt guided without being restrictively told everything to do. Additionally, the self-paced activities that allowed time flexibility and offered learning autonomy gave learners a sense of satisfaction and control over their learning. Across the FACS and CRISPR lab, we observed responses on the hard-to-grasp concept which impeded a satisfactory experience. Learners expressed dissatisfaction with inadequate explanations of difficult-to-grasp concepts in these laboratories and left feeling the need to have further laboratory sessions. The code: hard to grasp concept, was not observed in the cell culture lab.

> *"I enjoyed this experience and found it helpful, especially in regards to how to use the Biological Laminar Hood."*
> *"I think the overall concept of this lab was simply hard to grasp. This led me to be somewhat dissatisfied with this experience because I couldn't understand why we were performing each task."*

Research Question 2*: To what extent did the perceived utility value and tool efficacy of the VR lab modules predict learners' perceived satisfaction with the learning experience across different lab types?*
A stepwise multiple linear regression analysis was conducted to examine the contributions of the predictors. We used this method as it allows us to identify variables in our model that explain a significant amount of variance. Students' perceptions of utility value and tool efficacy were the predictor variables while perceived satisfaction was the outcome variable used in the model. We report the results of the model for each of the laboratories below.

Cell Culture VR Lab
A model based on utility value as a predictor of satisfaction was statistically significant, (F (1, 27) = 44.31, p = .000, R2 = .62, Adj. R2 = .61), indicating that participants' perception of the utility value of the VR labs accounted for 62% of the variance in participants responses to the satisfaction subscale. The model excluded perceptions of tool efficacy as it was not a statistically significant predictor of the variance in participants' responses on the satisfaction sub-scale. Results are shown in Table 5 below.

Table 5: Regression Model for Satisfaction in the Cell Culture VR Lab

Variables	B	SE of B	*Beta*	*T*	*VIF*	*F*	*R2*	*Adj R2*
Model 1								
Utility Value	*.64*	*.1*	*.79*	*1*	*1*			
						44.31	*.62*	*.61*

CRISPR VR Lab
A model based on tool efficacy as a predictor of satisfaction was statistically significant, (F (1, 27) = 121.33, p = .000, R2 = .82, Adj. R2 = .81), indicating that participants' perception of the tool efficacy of the VR labs accounted for 82% of the variance in participants responses to the satisfaction subscale. The model excluded perceptions of utility value as it was not a statistically significant predictor of the variance in participants' responses on the satisfaction sub-scale. Results are shown in Table 6 below.

Table 6: Regression Model for Satisfaction in the CRISPR VR Lab

Variables	B	SE of B	*Beta*	*T*	*VIF*	*F*	*R2*	*Adj R2*
Model 1								
Tool Efficacy	*1.1*	*.1*	*.90*	*.78*	*1.28*			
						121.33	*.82*	*.81*

FACS VR Lab
There was no statistically significant model as a predictor of satisfaction, indicating that participants' perception of the utility value and tool efficacy of the VR labs did not account for any of the variance in participants' responses to the satisfaction subscale. The model excluded perceptions of utility value and tool efficacy as they were not statistically significant predictors of the variance in participants' responses on the satisfaction sub-scale.

Discussion

This study investigates the role of context in virtual laboratory design by measuring differences in learners' perceptions of virtual laboratories, measured by the constructs tool efficacy, utility value, and satisfaction.

Across each of the VR laboratories, themes captured feelings of increased engagement, lecture reinforcement, and enhanced understanding among learners. Like Reeves, et al. [33] observed, learners in our study were able to build on classroom knowledge to navigate the virtual environment for concept application and improved understanding. Furthermore, we observed a direct comparison of the assumed physical laboratory experience with the VR lab experience in the learners' responses for all laboratories. This was a surprising finding, as most of the participants in the study had no previous experience with physical biomedical laboratories. We thus infer that the use of virtual learning environments can stimulate expectations of the physical component, leading to appreciation for or discontent with assumed differences.

While our quantitative data provides insufficient evidence for differences in learners' perceptions, our qualitative findings shed light on potential differences in perceptions with relation to topic difficulty (FACS and CRISPR). Klepsch and Seufert [34] highlight the importance of considering task complexity and recommend appropriate adjustments such as pre-training to enhance learners' prior knowledge for effective learning of the course material at hand. As VR laboratories can serve as a form of pre-training for physical laboratories, these findings reveal the need for improved scaffolding and varied forms of element interactivity based on topic complexity in designing effective learning environments.

Sasidharan and Kareem [35] reported that learners' perceptions of usefulness are majorly influenced by the relevance of course concepts to their future careers independent of perceived content difficulty. We observed related results in our data, as learners in our study expressed positive perceptions on the beneficial role i.e., utility value of laboratory concepts for their BME careers with non-reference to concept difficulty. In contrast, laboratory concept difficulty was recurringly mentioned in learners' perceptions of satisfaction and effectiveness of the VR labs for learning. This is like Utha, et al. [36] observation of the influential role of content difficulty in fostering positive or negative emotions during mathematics learning.

We infer that utility value accounted for a large variance in perceived satisfaction for the Cell Culture VR lab due to its perceived relevance as a foundational requirement for the BME field. This is represented in the theme, learning activity in which the Cell Culture lab concepts were perceived by learners to be a basic and important foundation for their overall success in BME. Higher satisfaction levels are experienced when learners perceive a direct link between course concept and career applicability [11, 35]. Similarly, perceived tool efficacy is inferred to have accounted for a large variance in perceived satisfaction for the CRISPR VR lab due to learners' awareness of its necessity for course exams despite limited knowledge as to its applicability for future industrial careers. This finding is based on conversations with the course instructor who mentioned that the CRISPR VR lab formed a major part of an assignment for the Tissue Engineering course.

The perceived high task complexity and limited knowledge of relevance of the FACS VR lab by learners in our study could have resulted in low motivation to engage with the laboratory environment thus influencing satisfaction levels [11]. This explains the inability of perceived utility value and tool efficacy to account for any variance in perceived satisfaction of the FACS VR lab. This is further reflected in the theme, laboratory technique development and learning activity where the FACS VR lab is reported to have had hard to grasp concepts resulting in an inability to replicate due to existing confusions. It is therefore recommended that relevance of course concept for course performance and real-world applicability is highlighted and interwoven into VR lab environments.

Conclusion

This study gives insights into the potential role of context and subject matter difficulty in shaping learners' perceptions of VR laboratories for BME education. Instructors can identify factors to look out for when choosing VR laboratory modules for classroom instruction, especially when they have many options to pick from without the autonomy of design. In working towards the effective integration of VR laboratories into BME classrooms, it is important that we take a deeper dive into student factors and their influencing attributes. Beyond setting objective learning outcomes to be achieved by students while using VR laboratories, it is impertinent that we engage our students on their lived experiences with VR environments to ensure that we are adequately catering to their learning needs for a well-rounded educational experience. Finally, our findings show the necessity of more research to be done on the role of context in designing virtual laboratory environments for positive and enhanced student experiences.

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