Student Satisfaction in Virtual Reality Laboratories

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***Abstract*—This research paper presents our findings from a mixed-method study investigating students' experiences in virtual reality (VR) laboratories that influence satisfaction levels toward increased learning engagement and outcomes. There has been increasing adoption of VR laboratories within higher education institutions to foster conceptual understanding and representation of abstract concepts. In ensuring their successful implementation for improved learning experiences, predictors and success factors for learners', satisfaction levels have been investigated. The underlying experiences of students in VR laboratories that influence satisfaction levels have been overlooked in most literature on student satisfaction. Although predictive models inform us as to factors that could impact satisfaction, they fall short in capturing the subjective experiences of learners in navigating virtual environments. These experiences offer useful insight into strategies for supporting learners during the implementation of VR laboratories for increased satisfaction levels. The purpose of our study is to investigate learners' experiences in multiple VR laboratories with regard to satisfaction. We implemented a series of VR laboratories into an undergraduate curriculum to offer learners a holistic learning experience. We adopt a mixed-method research design approach. The administered survey included a validated satisfaction survey and additional open-ended questions on the experience and satisfaction. We use results from the open-ended questions to interpret quantitative survey ratings. Our study provides insights into students' unique satisfaction experiences in virtual learning environments. Understanding these experiences could inform instructors on important strategies for supporting students during the implementation of VR laboratories. This could further ensure improved student engagement, learning satisfaction, and enhanced learning outcomes.**

***Index Terms*—Virtual Reality Laboratories, Student Satisfaction, Mixed Method**

I. Introduction

Laboratories are essential to engineering undergraduate and graduate education [1]. They are spaces where engineering students are introduced to practical demonstrations, research, and independent experimentation integral to engineering practice [2]. Laboratories are thus the avenue for scientific explorations where students connect theory and practice within the STEM curricula of higher education. Traditionally, students and instructors had to be physically present in a physical location with physical equipment to engage in laboratory instruction. This came with high monetary implications, logistic requirements, and inclusivity challenges, which limited the laboratory experience students received.

However, advances in computing technologies for distance learning have made it possible to facilitate alternative laboratory-based education for undergraduate engineering education [1]. For example, Virtual reality (VR) technology has been increasingly adopted in the form of instructional case studies and applied in engineering pedagogy owing to the immersive learning experience it offers for laboratory, programming, and design tasks [3]. VR laboratories are deployed over distant learning infrastructures to provide digital laboratory access that mitigates the several limitations of traditional physical laboratories. VR-based laboratories offer novel opportunities for educators to design innovative and engaging environments that significantly impact students' learning experiences when integrated into the engineering curriculum [2], [4].

Accordingly, scholars have investigated strategies and considerations for designing VR laboratory environments to facilitate beneficial student learning experiences. Among such considerations is facilitating a satisfactory learning experience—satisfaction has been positively correlated with engagement and students' course performance [5]. Various factors, such as technology quality, course flexibility, instructor response time, and technology self-efficacy, have been proposed to be significant predictors of student satisfaction in virtual learning environments [6]. Majorly, these studies overlook the subjective experiences of learners in navigating virtual environments beyond predictive models. These overlooked experiences offer useful insight into strategies for supporting learners during the implementation of VR laboratories for increased satisfaction levels [7].

In this study, we aimed to investigate students' satisfaction in a VR laboratory environment to gain insight into their satisfaction experiences beyond numeric ratings. We investigated learners' perception of satisfaction levels and influencing factors within a VR laboratory integrated into their course curriculum. To achieve our objectives, our guiding research question was, "What are students' perceptions of their satisfaction experiences within the administered VR laboratory environments?"

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II. Literature Review

A. Virtual Reality (VR) Laboratories

VR laboratories are immersive technologies that simulate physical laboratories, enabling students to manipulate equipment for intuitive interactions [1]. They provide access to laboratory instruction through student interaction with a virtual environment through immersive headsets or desktop simulations [2]. Amongst their affordances for science education, Potkonjak et al. [1] identified flexibility, multiple access, ease of modification, resistance to damage, and cost efficiency as significant advantages. VR laboratories have been used as preparatory, supplementary, and alternative to physical laboratories with observations of their effectiveness in fostering conceptual skills and affective learning experiences [4].

VR laboratories have been adopted in bioscience [5], biomedical engineering [6], and biochemical engineering [7] as a tool to provide efficient training for improving students' technical skills. In addition to technical skill development, researchers have explored the effect of VR on classroom instruction by studying students' VR learning experiences. Dyrberg et al. [8] report increased learners' motivation, confidence, and performance in physical laboratory experiments after participation in a preparatory VR laboratory environment. May et al. [9] also explored the effect of an electric circuit online laboratory on student motivation and self-regulation and observed a positive influence. These studies support existing empirical evidence for the effectiveness of VR laboratories for positive student engagement, motivation, and interest [10], [11].

Most studies of students' learning experiences in VR laboratories have proposed and tested predictive models of VR learning effectiveness – several studies also explored the effects of technology and instructor characteristics on VR learning [12], [13]. These models offer relevant insight into the design and implementation of VR laboratory environments in terms of usability, utility, and satisfaction. However, an in-depth understanding of how to support students in utilizing these environments for learning is still lacking.

B. Learner Satisfaction

Students' satisfaction with learning activities significantly contributes to the success of educational endeavors. Past research has linked satisfaction to learners' persistence because when learners are satisfied with their overall learning experiences, they are more likely to continue and succeed in their academic pursuits [14], [15]. Some researchers posit that satisfaction with the learning experience is often achieved when students' learning, cognitive, and social needs are met [16], [17]. While other constructs, such as cognitive engagement [18], [19], presence [20], [21] motivation [22], [23], and self-regulation [24], are essential to learning in virtual and online environments, learning satisfaction remains crucial across all educational settings.

Several dimensions of learning satisfaction have been studied in online and virtual learning environments. For example, Weidlich and Bastiaens [25], and Kranzow [26] suggest that students primarily derive satisfaction in online or virtual settings from their interactions with both the learning content and the instructor. Additionally, some other studies have found that instructors' attitudes [27], [28], learners' perceived usefulness [29], and interpersonal interaction [30] significantly contribute to learning satisfaction.

Past research has developed instruments for measuring online students' satisfaction to elucidate learning satisfaction in online and virtual learning environments [30]and in web-based e-learning systems [31]. Other studies have developed models and frameworks to understand students' satisfaction with VR learning better. For example, the studies by Sun et al. [32] and Aftab et al. [33] proposed an integrated model with six dimensions of student satisfaction with e-learning, including learners, instructors, courses, technology, design, and environment.

Furthermore, Martin and Bolliger [34] introduced an Online Learner Satisfaction (OLS) framework to enhance our understanding of satisfaction in online and virtual learning settings. The framework, derived from their comprehensive review of previous literature on online learning satisfaction, identified the themes of learner, course, instructor, program, and organization as the key aspects of online learner satisfaction that past studies examined. The studies' findings revealed that specific factors unique to their learning environments must be considered to improve learners' satisfaction. Hence, in our study, we investigate learners' satisfaction experience with themselves as learners, the course content, and the VR laboratory environment through a mixed-method approach.

III. Method

A. Course Content

The study focused on the experiences of students who enrolled in a Tissue Engineering course. The course is an elective for the undergraduate biological/biochemical engineering program. It aims to provide an understanding of the design and development of replacements for organs and tissues in the body. Majorly, undergraduate students in their third or fourth year select the course to explore different areas of the biomedical engineering field. The course provides a solid introduction to biomedical engineering research, leveraging the application of general sciences (chemistry, biology) and engineering concepts learned in prerequisite courses. The overarching goal of the course is to develop artificial tissues and organs that can be used to improve medical conditions faced by humans. These tissues can be used as replacements for damaged or diseased body parts in vivo or model systems for studying medical conditions in vitro. Additional course objectives include understanding tissue engineering principles for cell biology and materials science and developing tissue-engineered constructs.

B. VR Laboratories in the Study

We adopted Labster, a commercially available VR laboratory software. Five VR labs were administered for the

course: Cell Culture Basics, FACS, Gene Regulation, CRISPR, and Tissue Engineering, but due to incomplete responses, we excluded the Tissue Engineering VR laboratory. The VR laboratory was a desktop-based simulation that required students to log in to an interactive online platform. Students could use a mouse or desktop keypad to navigate the laboratory environment. They could view 3D representations of experiments, equipment, and laboratory techniques. The VR laboratories presented students with a real-world problem and walked them through the processes and techniques for solving it. For example, the Gene Regulation VR laboratory had a scenario on saving a visually impaired girl. Students were required to prepare induced pluripotent stem cells (iPSCs) from the patient's samples. They underwent an experimental protocol to measure the mRNA levels using a real-time reverse transcription polymerase chain reaction (RT-PCR) test and protein expression using Western blots. Key details on gene regulation equipment, stem cell information, and the development of stem cells were provided to learners. Sample images from the VR laboratories are in Figures 1 and 2.

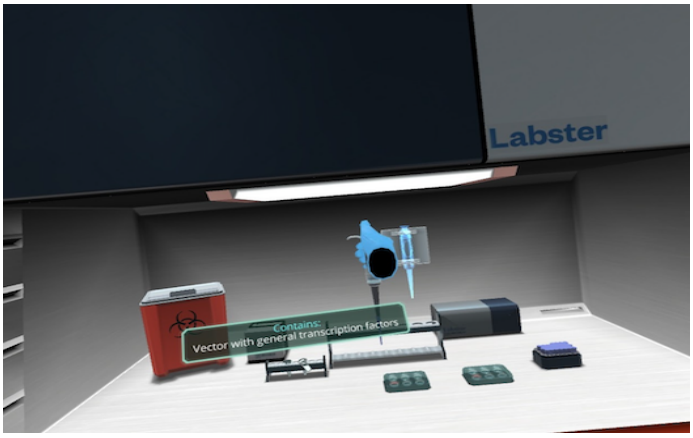

Fig. 1. Gene Regulation VR lab sample image from Labster website.

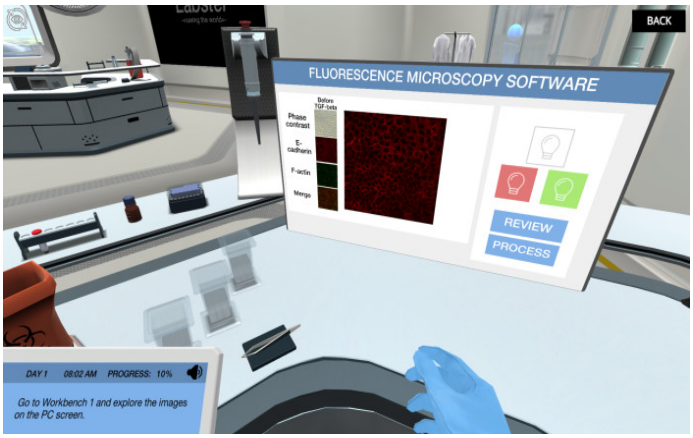

Fig. 2. CRISPR VR lab sample image from Labster website.

C. Perceived Satisfaction Survey

In assessing students' perceived satisfaction experiences of the administered VR laboratories, we adopted Chou and Liu [35] perceived satisfaction survey. The survey captured aspects of satisfaction that were revealed to be important for VR learning environments in our literature review. It contains seven statements (included in the appendix) and measures students' perception of their sense of contentment with the VR laboratory learning experience and environment. Survey statements were reworded for the different VR laboratories. For example, "I was satisfied with the overall learning effectiveness of the Gene Regulation virtual lab." A 5-point Likert scale with 1 as strongly disagree and 5 as strongly agree was used in the survey. Two open-ended questions – What factors influenced/contributed to your satisfaction/dissatisfaction in the VR laboratory? and What was your overall experience with the VR laboratory? were included as an additional item on the administered survey.

D. Study Procedure

Following approval from the Institutional Review Board (IRB), the perceived satisfaction survey with open-ended questions was administered to 41 students taking the Tissue Engineering course via Google Forms. The open-ended questions asked learners about their overall experience and factors influencing their environment. The survey was sent to the course instructor, who administered it as part of the course assignments.

Students received lectures on course concepts, with theory and application discussed using presentation slides. Upon completion of each lecture, which had a corresponding VR laboratory (as designed by the course instructor), students were given an assignment that included an assigned VR laboratory, a post-module activity, and a survey link. The post-module activity contained tasks that enabled learners to connect the VR laboratory instruction to the overall course objective.

E. Study Participants

Participants in this study were College of Engineering students at a public research university in the southeastern U.S. enrolled in a Tissue Engineering course. 26 of the responses received were included in this study based on consistency of responses and consent across the 4 VR laboratories. Our participants included 26 students—males (54%) and females (46%), the majority of which were in their 4th year (73%) of undergraduate study in biological engineering (57%), biochemical engineering (42%), and other (1%) majors.

IV. Results

We present descriptive statistics of our quantitative data followed by summary data of learners' Likert scale responses. The results of the thematic analysis of our qualitative data follow this.

The reliability of the satisfaction subscale was measured, and Cronbach's alpha ranged between .90 and .97, indicating high internal reliability. We present the descriptive statistics

and reliability coefficients of the satisfaction subscale for each of the VR laboratories in Table I and Figures 3–6.

TABLE I
DESCRIPTIVE STATISTICS (N=26)

VR Labs	CELL	GENE	FACS	CRISPR
Mean	3.86	3.66	3.75	3.48
S.D	.63	.75	.67	.96
Skewness	-1.35	-.95	-.57	-.93
Kurtosis	2.73	.82	.38	.38
Cronbach's Alpha	.90	.93	.90	.97

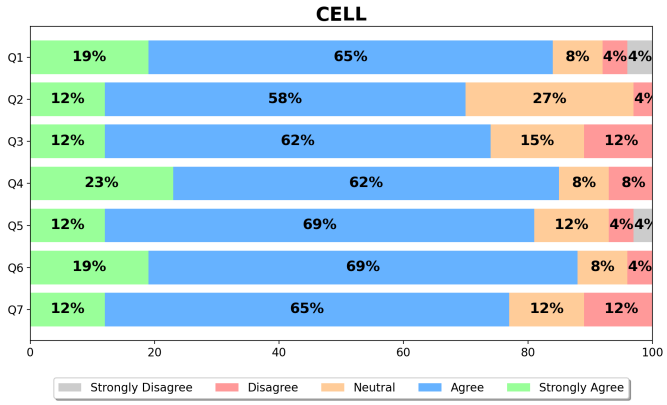

Fig. 3. Satisfaction Ratings for Cell Culture VR Lab.

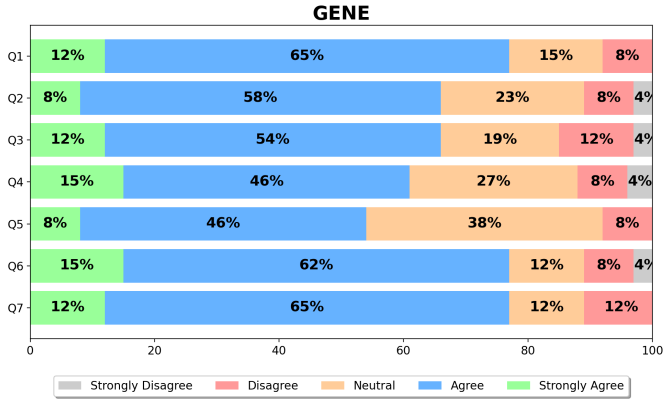

Fig. 4. Satisfaction Ratings for Gene Regulation VR Lab.

A. Qualitative Data

For each administered VR laboratory, we conducted a thematic analysis of learners' responses to open-ended questions on their overall experience and factors influencing satisfaction/dissatisfaction. We initially wanted to present our results for each VR lab just like we did in our quantitative data results. However, we observed that perceptions and experiences under generated themes for this study were similar. Variations and

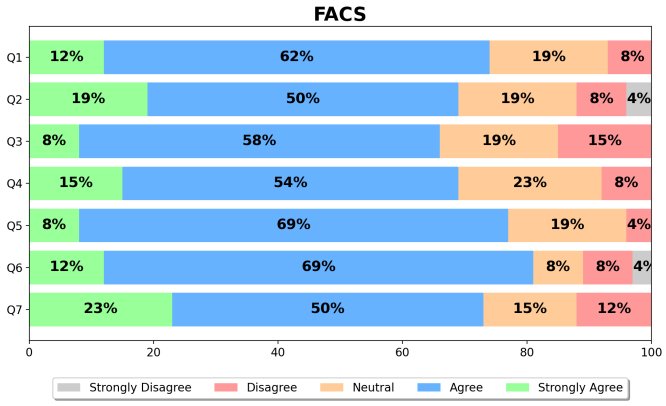

Fig. 5. Satisfaction Ratings for FACS VR Lab.

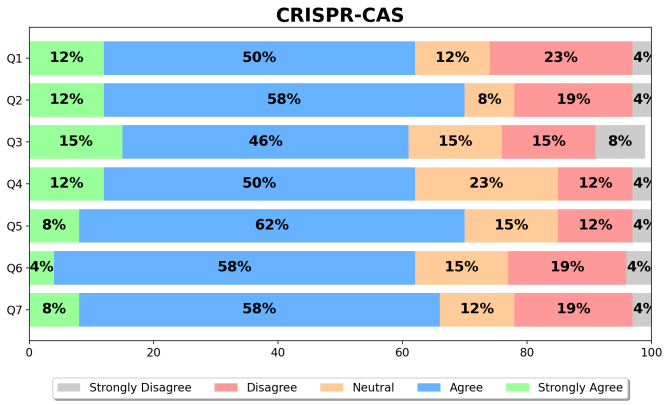

Fig. 6. Satisfaction Ratings for CRISPR-Cas VR Lab.

dissimilarities observed were beyond the scope of this study. Therefore, we report our findings under three broader themes observed to capture learners' descriptions of their satisfaction experiences: course context, VR environment, and learning impact. We present codes and provide sample quotes from our dataset that are in line with these themes.

1) Course Context: This describes learners' satisfaction with the specific context/concept of the VR laboratory. We observed a lower percentage of responses that fell under this theme. It emphasizes the impact of the content presentation on learners' satisfaction and engagement with the VR laboratories. With learners engaged in multiple laboratories, it was interesting to see them reference specific aspects of the experiments at different points. Recurring codes within this theme were course materials, explanations, instructions, and questions. Different learners wrote responses on the concept of each laboratory with emphasis on the supplemental information in the VR laboratory as helpful for interest. Learners reiterated their pleasure with the clear instructions and explanations of complex concepts. Furthermore, the varied format and perceived difficulty level of questions made learners feel constantly engaged, fostering higher satisfaction levels.

I think the genome sequencing "challenges" were

new and interesting way to learn.

The supplemental information to provide context as to why I was doing certain tasks had a positive impact on my experience and made me want to do more of these virtual lab experiences.

On the other hand, we observed a few unpleasant responses regarding how the experiment steps were presented, which impeded positive experiences. There seemed to be a preference for presentation styles of experiments that differed from what the VR labs offered among these learners.

I was not satisfied with the explanation of choosing a selected guide strand.

2) Learning Impact: This theme describes learners' expressed satisfaction/dissatisfaction with the impact of VR laboratory usage on their learning experience. Learners felt satisfied with their understanding and engagement with experiments due to using the VR laboratories. Recurring codes within this theme were learning autonomy, increased interest, and learning help. These codes were predominant across all laboratories, with learning help having higher representation.

The confidence and level of control learners experienced during the VR laboratory experiments fostered positive feelings within them as they made mistakes and figured out ways to correct them, making them feel challenged. Furthermore, learners commented on how their satisfaction with the simulation and visuals enhanced their understanding of concepts as they could engage in an interactive form of learning deeply.

I would say that my experience with this lab was good because I am a visual learner and there were a lot of images that helped me understand the process of what I was doing.

I was satisfied with the experiment and information as a whole I feel it was very well integrated and promoted my understanding and learning of the material.

A few learners commented on the impact of the COVID-19 pandemic on their experience. They had spent a major part of their time learning online and had come to have trouble engaging with virtual environments. On the other hand, some learners experienced dissatisfaction and frustration in their interactions with the VR laboratories due to moments of confusion with experiment instructions.

I just cannot bring myself to do more virtual learning after 2.5 years of online school (1.5 here, 1 abroad) and have an incredibly hard time engaging with online learning content after having to do so much of it for nearly three years.

3) VR environment: We describe this theme as learners' responses specific to features of the VR environment that impacted their satisfaction experience. Across the multiple laboratories, we consistently observed a reference to technical capabilities independent of course content and learning impacts. The predominant codes within this theme were aesthetics, time reference, and feature assistance. The aesthetics, which cover images, animations, videos, and visual representation of the VR lab environment, were perceived to be well suited for viewing the varied experiments without boredom. The ability to choose a convenient time, pause, take a break, and continue one's progress while carrying out experiments positively affected learners' satisfaction. In addition, the virtual assistant and the fast-tracked experimentation timing were indicated by learners as helpful for their positive engagement. Overall, the VR laboratory interface's easy-to-use and learn nature positively impacted learner satisfaction.

I would say that my experience with this lab was good because I am a visual learner and there were a lot of images that helped me understand the process of what I was doing.

I like how it explains each step and that you don't have to wait actual times when the experiment has to run for a certain amount of time.

Like other themes, there were a few negative feelings about the technical performance of the VR laboratories and their attention to detail causing a slow pace for experimentation.

The time that it takes to complete the assignment is a big factor in satisfaction because I prefer a lab that goes straight into the point of the experiment.

V. Discussion

Our study found that students had a positive experience and were generally satisfied with using the VR laboratories. This is reflected in the quantitative ratings, which show over 60% (strongly agree and agree) agreement to satisfaction items across the multiple VR laboratories except the Gene Regulation VR laboratory. This informs us of the VR laboratories' capability to offer a high-satisfaction learning experience to students. To capture learner satisfaction holistically, we use our qualitative results to provide insights into aspects of the learning experience that impacted satisfaction.

Specifically, students perceived the course context, learning impact, and technology environment as shaping their satisfaction experience and expressed this consistently across all VR laboratories. This observation is complemented by existing literature on learner satisfaction in online environments. Martin and Bolliger [34] framework on learner satisfaction in online environments conceptualizes the learner, course, technology, and instructor as critical aspects for holistically understanding students' experiences. Similarly, learners' perception of technology interface, subject matter content, and learner personalization were observed to be valid predictors of learner satisfaction in technology-mediated environments [36].

Clarity of instructions and evaluation format in online learning environments has been observed in the literature to influence learners' satisfaction [37], [38] significantly. In our study, we also found that clarity of instructions and having questions on the course material was appreciated by students for enhancing enjoyment and engagement in the VR laboratory. Unclear or confusing instructions garnered feelings of frustration, annoyance, and disengagement among learners,

which Rajabalee and Santally [39] observed to be negatively correlated with student engagement and overall performance.

Additionally, the design and length of the technology environment impact learners' satisfaction as visually pleasing, interactive, and concise content stimulates interest more than monotonous and lengthy designs [40]. This complements our findings as learners consistently referenced the simulations, visuals in the form of images, and length of sessions as major influences for their positive satisfaction. Also, Martin and Bolliger [34] capture instructional design and course technologies as significant factors in fostering positive satisfaction experiences in online environments. As online learning environments, VR laboratories offer an interactive interface that must be designed with descriptive animations of equipment and experiments to enhance student satisfaction. Negligence of the length and aesthetical interface of VR laboratory environments could impede positive satisfaction experiences and cause disengagement in learners.

In his model for assessing learning satisfaction with e-learning environments, Wang [36] conceptualized learner personalization as the ability for learners to feel a choice and control over their learning and learning progress. Our findings reflected this as learners discussed their satisfaction experience specific to its impact on their learning experiences and outcomes. Perceived learner autonomy, which allowed them to make mistakes and figure out steps to correct them, was a positive influence that made learners feel challenged and confident in their knowledge. When balanced with preparation, students' feeling of putting in efforts to learn and being challenged results in increased engagement and satisfaction [41]. This bears similarity to our findings as preparation in our study showed up in course context as explanations while challenge and efforts showed up in learning impact as learner autonomy. Enabling learners to move from passive to active participants of experiments who figure things out with the right support has the potential to increase positive satisfaction.

Although satisfaction and learning outcomes have been reported to be positively correlated, the question of whether we can use students' satisfaction to learn about the benefits of the environment for learning outcomes exists. In other words, students can be satisfied but still lack the learning needed in an educational experience. Ensuring positive satisfaction experiences positions students to better engage with the learning environment and achieve learning outcomes through effective pedagogical strategies.

VI. Conclusion and Future Directions

Through this mixed-method study, we intended to gain insight into learners' satisfaction experiences in VR laboratory environments beyond quantitative ratings and predictive factors. Our quantitative data showed a generally positive satisfaction experience among students, which was majorly influenced by their perceived course context, technology environment, and learning impact of the VR laboratories (qualitative data). These themes align with existing studies on learner satisfaction in online learning environments.

Our findings show the need for balance and personalized support when implementing and designing VR laboratory environments with these factors, as a small subset of learners found them to be causes of dissatisfaction and disengagement. These findings offer a guide for engineering instructors and instructional designers in improving the satisfaction experience of students while navigating complex experiments in virtual spaces. However, we recommend caution when interpreting our findings due to the small sample size. We encourage researchers to further explore student's satisfaction experiences in virtual reality laboratory environments for enhanced learning engagement and performance.

With the increasing attention to the use of artificial intelligence for designing learning content for increased student outcomes, their integration into VR laboratory environments could open the doors for catering to individuals based on their learning characteristics (prior experiences and knowledge). This could serve as a form of instructor support, an aspect of the Martin and Bolliger [34] satisfaction framework that was absent in our findings. We recommend that future studies investigate how students experience satisfaction when exposed to physical and VR laboratory environments for similar experiments. What aspects of this triangulating setup influence their satisfaction with improved engagement and learning outcomes?

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APPENDIX

Perceived Satisfaction Survey Questions.

- **Question 1**: I was satisfied with the teaching methods in the Gene Regulation virtual lab learning environment.
- **Question 2**: Overall, I was satisfied with the effectiveness of the VR lab to support learning.
- **Question 3**: I was satisfied with the virtual lab learning experience.
- **Question 4**: I think learning in the VR lab was beneficial for my learning.
- **Question 5**: A wide variety of learning materials was provided in the virtual lab learning environment.
- **Question 6**: I was satisfied with the information I gained in the VR lab learning environment.
- **Question 7**: Question 7; I was satisfied with the virtual lab learning environment.