The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #42082

Board 365: Relating Sociocultural Identities to What Students Perceive as Valuable to their Professional and Learning Efficacy When Engaging in Virtual Engineering Labs

Dr. Kimberly Cook-Chennault, Rutgers, The State University of New Jersey

Kimberly Cook-Chennault is an Associate Professor in the Mechanical and Aerospace Engineering Department at Rutgers University. She holds BS and MS degrees in Mechanical Engineering from the University of Michigan and Stanford University respectively; an

Ahmad Farooq, Rutgers, The State University of New Jersey

Relating Sociocultural Identities to What Students Perceive as Valuable to their Professional and Learning Efficacy When Engaging in Virtual Engineering Labs

Abstract

Virtual, online, and digital learning tools can be used to provide equity in access to STEM knowledge. These tools also serve as the building blocks for personalized learning platforms. The assessment instrument, Student Perceived Value of an Engineering Laboratory (SPVEL) was developed to ascertain the impact and efficacy of virtual and in-person engineering laboratories in 21st-century undergraduate curriculum. SPVEL addresses an emerging need for assessing engineering labs that take place in a myriad of environments in higher education, i.e., in-person, virtual, and hybrid. Due to the vast array of technological advancements over the last decade, SPVEL addresses the need to holistically examine instructional content, instructor communication, and student perceptions of value and motivation to learn from in-person and virtual lab environments. For this work, the SPVEL was used to evaluate student perceptions of a LabVIEW laboratory to understand student motivation, experiences, and performance (grades).

Theoretical Frameworks

SPVEL is premised on three theoretical frameworks: the Technology Acceptance Model, Astin's Input-Environment-Output (IEO) Conceptual Model, and Engineering Role Identity. SPVEL is unique because it extends beyond traditional course evaluation instruments that focus on instructor preparedness and ability to teach course content. Instead, the SPVEL connects students' 1) appreciation for laboratory discipline content and relevance to their career aspirations, 2) engineering role identity development as a function of participation within the lab, and student sociocultural identities (race, ethnicity, and gender).

Research Question

SPVEL was used to answer two research questions. How do student's sociocultural identity characteristics relate to their perceptions of value in a virtual engineering lab? How are students' perceptions of virtual lab value related to the sociocultural identities and lab report grades?

Research Methodology and Environment

This study was conducted in a capstone senior Mechanical and Aerospace engineering laboratory course within a virtual learning (VL) setting at a university in the northeastern United States with 227 undergraduate engineering participants. A quantitative analysis of variance (ANOVA) was performed on the dependent list of the twenty-six items of the SPVEL, where the factors considered were race/ethnicity and gender.

Findings

Statistically significant differences ($p < 0.05$) were found in student's perception of several variables, including the VL's ability to replace physical labs, student's friends seeing them as an engineer, student self-identification as an engineer, VLs being good learning tools, and prior experience of high school VLs. From the post hoc tests performed using the Games-Howell procedure, it was revealed that LatinX/Hispanic American students strongly believed that VLs could replace in-person labs and that African American students found VLs to be good learning tools and indicated engineering as an essential part of their self-image to higher degrees than other race/ethnicity student populations.

Implications for Practice

Studies such as these are critical in elucidating how laboratory environments affirm (or do not affirm) students' positionality in engineering. Furthermore, this work helps educators as they contemplate evidence-based practices for updating and modernizing laboratory equipment, protocols, and subject matter in innovative, novel ways. Lastly, this study works to build student-

centered personalized learning approaches that are needed to customize learning for each student's strengths, needs, skills, and interests.

1. Introduction

1.1. What are virtual laboratories?

Online learning modules and virtual laboratory (VL) platforms have been designed, developed, and studied as tools in many classrooms for several decades to enhance student engagement and academic performance in K-12, undergraduate (UG) and graduate (GR) populations. Over the last several decades the study and use of virtual lab technologies has increased in use and interest. Virtual laboratories (VLs) use media formats to replicate physical activities, equipment, tools, tests, procedures, and interactions that occur within a physical laboratory environment so that the learner/user can perform or observe experiments without being in the physical lab environment. VLs are typically classified in two ways. One classification of VL is a computer simulation of a real laboratory experiment that is accessed online. The second type of VL engages the user by providing remote access, control, operation, and/or observation of physical laboratory operation. The latter form of VL may also allow the user to observe real equipment, computers, and data capture through the internet. The ways in which these virtual and remote learning environments and tools are used varies and they have been extensively studied in primary, middle, high school, and secondary educational environments.

There has been a great deal of research on VLs in science, technology, engineering, and mathematics (STEM) disciplines in UG classrooms, e.g., in biology [1, 2], chemistry [3, 4], physics [5], computer science [4, 6], general engineering [7, 8], software and electrical engineering [6, 9-21], mechanical engineering (ME) [22-30], chemical engineering [31, 32], computer aided design [33], power engineering [34, 35], biomedical [36, 37] engineering, and aerospace engineering [38]. In physical sciences and engineering research in higher education, the study of virtual labs (VL) has generally focused on case studies about their implementation into classrooms or the engineering design process and design of virtual lab software and hardware. For example, VLs have been used to supplement traditional course materials in large-scale lecture classes or distance learning courses, to enhance lecture demonstrations, to prepare students for in-person action-oriented labs prior to engaging in the physical lab, to replace in-person labs, and to assess the performance of a student's ability to operate equipment and apply theoretical knowledge in performing practical tasks, e.g., [1, 37, 39, 40]. VLs have also been used to visualize complex physical phenomena, such as thermodynamic cycles and energy conversion systems, to optimize design efficiency and output [41]. Due to the variability in how these VLs have been used and studied, a myriad of methods has been used to evaluate their effectiveness, e.g., student outcomes (skills required for the Accreditation Board for Engineering and Technology), assessment of educational value as a function students' perceived motivation to learn, and students' *acceptance of new technologies* (ease of use and usefulness, i.e., the Technology Acceptance Model).

Many scholars contend that virtual, online, and digital educational laboratories can provide equity in access to STEM knowledge [42-45] due to their cost-effectiveness; replicability of experimental results and outcomes from operations; safety; enhanced visualization; potential for integration of technology, flexibility in VL design, and relative *ease of instructor* online dissemination to students [46-48], while others caution that use of these tools in educational environments could exacerbate *online and educational penalties* without careful consideration of the needs, strengths, weaknesses of students, and in particular, vulnerable student populations *[45*, *49].* An *online penalty* refers to disadvantages faced by certain groups of students that arise due to limited access to or ineffective use/experience with technology and online resources [49, 50]. *Online penalties* have been found to be minimal for high-achieving, affluent learners, learners with prior internships, and access to reliable internet and computer technologies. On the other hand, online penalties are enhanced and exacerbated for learners with less reliable internet from rural and/ or low socioeconomic communities; students with lower prior *successful* academic achievement; younger; and marginalized racial/ethnic groups in STEM. In the wake of the COVID pandemic, the elements contributing to *online penalties* have been studied by researchers to identify, access/evaluate, and alleviate these obstacles. For example, many states are partnering with school districts to provide free and low-cost internet options [51], some companies are also offering internet and hotspot services based on economic need to students, school administrators, and educators [52] and many libraries and state wi-fi locations offer free internet access [53-55]. Other researchers have identified that inclusivity in digital learning and VLs, will require the provision of special education and 504 services/features (subtitles, screen reader friendly, large fonts, audiovisual tools, etc.), culturally responsive and sustainable software/platforms/tools designs, and methods of VL assessment to understand how these tools meet or do not meet the needs of unique and diverse populations of students. Finally, many scholars contend that VLs and digital learning communities offer several benefits to diverse student learning communities, e.g. flexible learning (synchronous and asynchronous learning), expansion of learning opportunities (risk-free experimentation with dangerous or expensive materials, where students can be provided access to environments where they would otherwise be restricted), enhanced engagement and motivation through adaptive learning and inclusive learning environments. Thus, VLs could theoretically provide a pathway towards personalized learning, which is one of the 14 Grand Challenges for Engineering identified by the National Academy of Engineering [56]. Virtual, online, and digital learning tools can be used to provide equity in access to STEM knowledge, where these tools can serve as the building blocks for personalized learning platforms.

1.1. What is personalized learning?

The concept of *personalized learning* is not credited to any specific scientist, engineer, or scholar however, it has evolved over time with contributions from many educators, researchers, and educational theorists, such as Bloom [57], Dewey [58], Skinner [59], Montessori [60], and Pane et al. [61]. Personalized learning is an educational approach that centers on tailoring instructional methods, content, and pace of learning to meet individual needs, preferences, interests, and abilities (strengths, weaknesses, motivation). In this way, personalized learning approaches and tools seek to provide customizable, flexible, and adaptable learning environments for students. For example, Bloom and others [57, 62] investigated the effectiveness of one-on-one tutoring compared to traditional classroom instruction environments, and found that one-on-one tutoring enhanced the efficacy of the teacher and learner relationships, where teachers were able to customize content and pedagogical manner according to the students strengths and needs, and could better assist students with negotiating issues of student dependency for learning and self-sufficiency. Bloom also found that inequity in classroom dynamics where teachers designed curriculum and engaged primarily with top achieving students could be alleviated with one-on-one tutoring. Others such as Dewey, emphasized the importance of student centered learning experiences that could be tailored to student interests and needs [58], which were evidenced via student inquiry and active participation. Montessori's trailblazing work [60] revolutionized educational environments, where her method focused on individual development and self-directed learning, and emphasized freedom of movement and choice, which many scholars today believe is potentially beneficial for neurodivergent students who may struggle with traditional rigid classroom structures [63-65].

The aforementioned techniques and recommendations that contribute to personalized learning theory continue to be readily employed today where a conventional personalized learning models vary [66]. However, personalized learning models that focus on student, teacher, and learning environments and interactions that do not incorporate computer software and algorithms typically consider five elements: learner profiles, personal learning paths, individual mastery (competency-based progression), student agency, and flexible learning environments [61, 67, 68]. Learner profiles include personal student data such as individual skills, strengths, weaknesses, gaps, interests, and aspirations. Personal learning paths are defined as the unique learning pathways of students that can be aligned with and informed by learner profile information. Individual Mastery (competency-based progression) includes the continuous assessment of student's progress in content mastery according to clearly articulated standards and goals, where advancement occurs at the pace of the student. Flexible learning environments require instructors to consider and include multiple options and approaches in their delivery of course materials to support students' learning. Finally, the Student Agency component of personalized learning emphasizes student engagement in the design and involvement in their learning process.

The vision of the NAE's Grand Engineering Challenge of personalized learning extends beyond these elements, where the incorporation of advanced technology, artificial intelligence, and automation/simulation will facilitate seamless student assessment and real-time feedback for knowledge acquisition [56]. This enhanced interpretation of personalized learning includes the former elements in addition to technology integration that may include adaptive software, online resources, and interactive platforms. Since learning is shaped by personal experiences, cognitive awareness/engagement, cultural background, and environment [69], 21st century personalized learning models' building blocks should consider the perceptions of diverse student populations. In this way, this project's analysis of student's experiences, perceptions of value, and engagement with learning technologies when participating in a virtual engineering laboratory is examined using a validated engineering assessment instrument, Students' Perceived Value of Engineering Laboratories (SPVEL) to understand how different student profile metrics can be used to inform personalized learning models of the future.

2. Theoretical Frameworks in the Development the Student Perceived Value of an Engineering Laboratory (SPVEL)

2.1. What is the SPVEL and how is it useful?

The assessment instrument, Student Perceived Value of an Engineering Laboratory (SPVEL)[48, 70] was developed to understand the impact and efficacy of virtual engineering laboratories within a 21st-century undergraduate curriculum. This assessment instrument was developed due the need for a validated assessment instrument that allows for the comparison of virtual and in-person laboratory settings. Thus, the SPVEL addresses an emerging need for assessing engineering labs that take place in a myriad of environments in higher education, i.e., in-person, virtual, and hybrid. It also holistically allows an instructor or VL designer to examine how students experience discipline specific content, instructor communication, and assess how students perceive the laboratory learning experience to have (or not have) value in terms of their personal learning path and career development pursuits. The SPVEL is informed by three theoretical frameworks, i.e., the Technology Acceptance Model (TAM), Inputs- Environment-Outcome (IEO)

Conceptual Model, and Engineering Role Identity (ERI). SPVEL is unique because it extends beyond traditional course evaluation instruments that focus on instructor preparedness and ability to teach course content. Instead, the SPVEL connects students' 1) appreciation for laboratory discipline content and relevance to their career aspirations, 2) engineering role identity development as a function of participation within the lab, and student sociocultural identities (race, ethnicity, and gender). It is hypothesized that this assessment instrument can be used in understanding how students' Learner Profiles may relate to their Personal Learning Paths and Student Agency, which will be valuable in establishing PL models that are strength-based and affirming of students' engineering role identities [71].

2.2. Theoretical Frameworks that inform SPVEL

The SPVEL is informed by the three theoretical frameworks, e.g., the Technology Acceptance Model, Inputs-Environment-Outcome Conceptual Model, and the Engineering Role Identity. The Technology Acceptance Model (TAM), developed by Davis [72, 73], posits that peoples' adoption of information technological systems is connected to and a function of users' *perceived usefulness* and the *perceived ease of use* of the technological system. Thus, the TAM asserts that people will use or not use an application/tool to the degree they believe it will help them *do* their jobs better [72], and if people believe the effort to use the tool is too high or consider its benefits to be less than the effort of use, they will abandon the use of the technology. Several studies have used the TAM to explore students' decisions to use VLs [74-76]. Most researchers assert that the TAM is most effective when other variables are considered. The TAM has been expanded to better define usefulness where, it has been found that undergraduate engineering students associate more value, i.e., usefulness from educational technologies that allow them to connect their real-world experiences and theoretical knowledge to their perceptions of the real world engineering profession [77-79]. For this study, elements from this model will be used to understand how students value or do not the virtual lab as an educational tool (course content, delivery mode, instructional environment) and mechanism for communication with the course instructor.

Astin's Inputs-Environment-Outcome (IEO) conceptual framework [80] examines how inputs (characteristics and attributes (Learner Profile), i.e., prior experiences, socioeconomic background, race, gender, etc.) and the learning environment (formal and informal elements of the institution, i.e., curriculum, teaching pedagogical approaches, extracurricular activities, and prior learning experiences such as internships, and interactions with peers and faculty) influence student outcomes. Outcomes are defined as the changes that occur in the student because of their educational experiences, such as learning and developmental outcomes. The majority of the literature that uses the IEO conceptual model has focused on the examination of student success as a function of input variables such as learning disabilities [81, 82], amount and quality of time of involvement [80], perceived academic ability and drive to achieve [83], in UG and postsecondary level students. The IEO model has also been used to investigate the role of gender and race in the prediction of gender-role traditionalism [84], feminist identity and program characteristic roles in social advocacy [85] and differences in transition of black and white students from high school (HS) to college [86]. For this project, the IEO examines inputs such as prior coursework, internship, and virtual laboratory experiences and sociocultural identities, e.g., race/ethnicity, gender, student output grades; and environmental factors such as the virtual lab environment, materials, and communication with the instructor.

Engineering role identity (ERI) describes how students form their identities in the engineering role based on their experiences working in a community of practice and in the college environment.

Godwin *et al.* [87, 88] defined *engineering role identity* as how students describe themselves and are *positioned by others into* the role of an engineer. ERI is premised on three components, i.e., the dialogic nature of student's development of identity [89]; students' interest in the subject and beliefs about their competence relating to the subject [90, 91], and students' ability to comprehend concepts and connect new knowledge to prior information [92, 93]. These three elements within the ERI **influence students' motivation to persist in and learn about an engineering subject**. Many studies have shown engineering identity as a predictor of students' educational and professional persistence. Thus, this theoretical framework's inclusion allows the SPVEL to relate student learning profiles, formal and informal learning to their development and formation into engineers. For example, it was found that there are significant gender differences in how first-year students identify with engineering and becoming an engineer, where fewer women were exposed to the engineering field through applied or building experiences (0% women to 26% men); interactions with relatives who were engineers (20% women to 26% men) and STEM activities (10% women to 26% men) [94]. Thus, inclusion of the ERI in the SPVEL highlights how aspects of a VL learning tool could drive/motivate the engineering formation process and provide fruitful information that can be used to understand *how to personalize and provide meaningful choices* for young people's development into engineers.

3. Research questions

The SPVEL was used to answer two research questions. How do student's sociocultural identity characteristics relate to their perceptions of value in a virtual engineering lab? How are students' perceptions of virtual lab value related to the sociocultural identities and lab report grades?

4. Research Method and Environment

4.1. Data Collection Protocol

A Quantitative Research Design Method [95] was proposed and approved by the primary Institutional Review Board (IRB) of the authors. The study took place at a Research-1 [96], research-intensive institution in the Northeastern region of the United States. Two hundred and twenty-seven undergraduate Mechanical and Aerospace engineering students participated in this study where a LabView laboratory was conducted virtually. Students completed a pre-lab survey to capture aspects of their prior perceptions to virtual laboratories (VLs) and sociocultural characteristics such as race/ethnicity and gender. Students completed the post-lab survey after submitting their laboratory report that was submitted two weeks after the completion of the lab.

Due to the large number of students enrolled in the course, students were divided into multiple sections and were rotated in different sections of the LabView lab. Students participated in one introductory laboratory lecture that discussed course objectives, design, and expectations prior to participation in the LabView Lab. The pre-lab survey (SPVEL) questionnaire with the questions detailed in Table 1. After finishing the pre-lab questionnaire, students downloaded and observed a pre-recorded video lecture that described the theoretical concepts covered in each lab. These recorded lectures were created by instructors who taught the theory associated in the lab in the technical courses. These technical lab course content lectures reviewed concepts that are pre-requisites to the senior educational engineering lab. Students were also provided equipment manuals and laboratory guides for each lab prior to beginning the lab.

In the virtual laboratories, students observed the teaching assistant (TA) conduct the lab synchronously via multiple video feeds while logged on to a video conference platform. A schematic of the virtual lab set up is provided in Figure 1. As depicted in Figure 1, several cameras focused on specific aspects of the equipment where inputs were provided, and where data was captured as output. Students observed the operation of the equipment synchronously as the TA directed the lab procedures. In some cases, TA's asked students to indicate the steps in the procedure and/or express parameters for operation. Students were given two weeks to submit a laboratory report after participating in the lab. Students were prompted to complete a post-lab survey (SPVEL) after each lab with the questions detailed in Table 2.

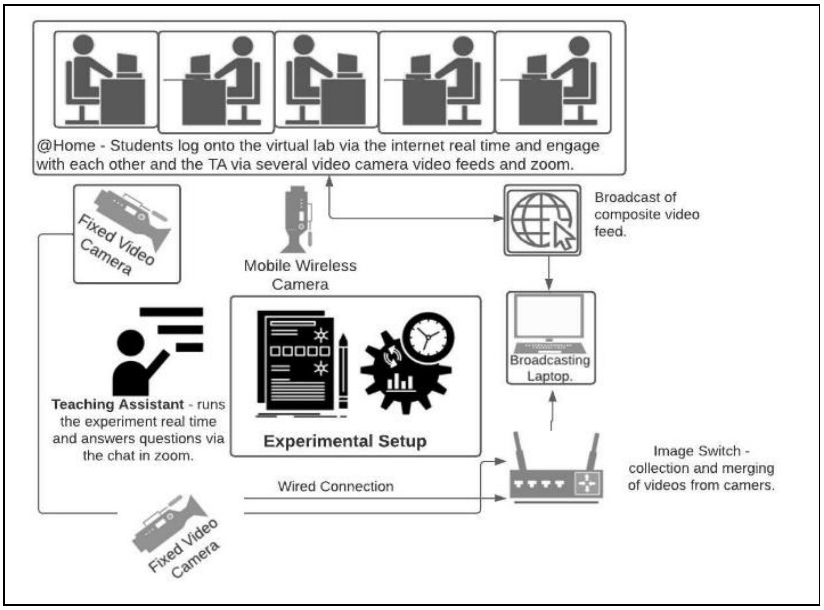

Figure 1. Illustration of the virtual laboratory experimental setup for the study [48].

Table 1. Pre-lab questions from the SPVEL administered before participation in the virtual laboratory, where the responses are provided in terms of a Likert Scale of *where 1 is Strongly Disagree, 3 is Neither Disagree nor Agree, 5 is Strongly Agree*

Item	Category of Question and Responses	Theoretical Model
Prior virtual lab experiences - demographic information. Possible student choices: 0 Classes (0), 1 – 2		
Q1	Have you ever engaged in a virtual lab in high school?	**IEO Model**
Q2	Have you every engaged in a virtual lab in college?	
Q3	How many in-person lab courses have you had since you started	
Prior internship and undergraduate research experience. Possible choices: None (0), 1 – 2 experiences (1), and 3+ experiences (2)		
Q4	Engineering internship	**IEO Model**
Q5	Engineering research with engineering school	
Prior experience - lab preparation classes other than MAE 14-650-431 (this course). Possible choices: 0 – 1 hour (1), 2 – 3 hours (2), 4 – 5 hours (3), 6 or more hours (4), N/A (5)		
Q6	How many hours have you spent in the past preparing for hands-on labs.	**IEO Model**
Q7	How many hours have you spent writing lab reports (outside of class period) in college in the past (hands-on labs)?	
Perceptions of virtual labs (VLs) – Likert Scale of 1 to 5. Possible choices: Strongly Agree (5), Somewhat Agree (4), Neither Agree nor Disagree (3), Somewhat Disagree (2), Strongly Disagree (1)		
Q8	I think VLs can be good learning tools.	**IEO**
Q9	I think virtual labs can replace hands-on-labs.	
Q10	I think virtual labs are easier to do than hands-on-labs.	
Q11	I can learn as much virtual lab as I can from a hands-on-lab.	
Q12	The skills from VLs will be useful to me in my future career.	
Self-Identification with the Engineering Profession- Likert Scale of 1 to 5. Possible choices: Strongly Agree (5), Somewhat Agree (4), Neither Agree nor Disagree (3), Somewhat Disagree (2), Strongly Disagree (1)		
Q13	I can understand concepts that I have studied in engineering.	**Engineering Role Identity**
Q14	Being an engineer is an important part of my self-image.	
Q15	My friends see me as an engineer.	

Table 2: post-lab questions administered to students after they completed the virtual lab and submitted the final laboratory report from the SPVEL, N=227. *Likert Scale of 1 to 5 where 1 is Strongly Disagree, 3 is Neither Disagree nor Agree, 5 is Strongly Agree*

Item	Category of Question and Responses	Theoretical Model
Student Perceptions of VL Experience.		
Q16	The VL was easy to understand.	**TAM +**
Q17	I could follow the steps in the lab.	
Q18	The lab held my attention for the full duration of the time.	
Q19	I was able to communicate with the TAs during the lab.	
Q20	Class ran smoothly with no technical glitches.	
Q21	This lab adequately prepared me to write my final report.	
Q22	TAs effectively answered questions during the lab.	
LabView virtual laboratory (VL) and in-person interactions and visual experiences.		
Q23	The operations performed in the lab were easy to follow.	**TAM +**
Q24	It was hard for me to see relevant steps/processes taking place in the lab.	
Q25	I was able to ask questions in the virtual chat.	
Q26	I was able to ask the TA questions orally during the lab.	
Q27	I think I learned as much from this VL as I would have learned in a hands-on lab.	
VL Connection with MAE prior coursework		
Q28	This VL helped me to understand concepts from my previous courses.	**IEO Model +**
Q29	This VL affirmed concepts from my previous classes.	
Q30	This VL helped me make the connections between previous course concepts.	
Q31	The VL motivated me to want to seek more knowledge about this subject outside of class.	
Q32	I was able to interpret the data from the lab using only resources provided in the class.	
Usefulness of the virtual lab for future career		
Q33	I do not think that the real life of an engineer was reflected in this VL.	**TAM +**
Q34	The virtual Lab was a good learning experience.	
Q35	I think the skills I learned in this lab will be useful in my future career.	

4.2. Quantitative Data Analysis

In this research study, data analysis was quantitative where the goal was to investigate the factors influencing technology acceptance of virtual labs among undergraduate engineering students, considering their sociocultural characteristics, prior experiences, and identification with the engineering field. This approach was informed by three theoretical frameworks of the Technology Acceptance Model (TAM), Input-Environment-Outputs (IEO) Conceptual Model, and Engineering Role Identity that were used in the development and validation of the SPVEL assessment instrument. The survey instrument was designed to capture respondents' perceptions of technology usefulness and ease of use (TAM constructs), environmental inputs impacting technology adoption, and their engineering role identity. Descriptive statistics, including means and standard deviations, were computed to provide a comprehensive overview of the survey responses.

In addition to determining the descriptive statistics, a test for normality was performed to determine whether parametric or non-parametric statistical analysis approaches could be used. The normality tests were performed on the collected Likert scale data from the SPVEL instrument considering the 26 variables validated from the questions from the SPVEL. For this analysis, a Shapiro-Wilk test for normality was performed and the significance, p-value was computed.

Leven's Test of Equality of Variances was also computed to ascertain the homogeneity of variance between the groups [97]. The null hypothesis for this test was that the sample sizes of the groups studied would have equal variances between them. If the test produced a non-significant p-value then the test groups are said to have equal sample sizes (equal variance between them). However, if the p-value is significant, the null hypothesis is to be rejected, variances of sample size groups is confirmed.

An analysis of variance (ANOVA) was also performed to assess the significance of variations in technology acceptance across different racial/ethnic sociocultural identities. This approach aligns with recommendations from [98] for utilizing ANOVA in the examination of group differences. The integration of these frameworks and statistical techniques allows for a nuanced exploration of the complex interplay between technology acceptance, environmental influences, and engineering identity within the professional context [99-101]. This comprehensive approach not only enhances our understanding of technology adoption but also sheds light on the distinct roles and perspectives of engineers in shaping technological outcomes and provides essential knowledge needed for the development of evidence-based personalized learning models that will inform personalized learning systems and platforms.

Finally, a Games-Howell post-hoc test was conducted [102]. The Games-Howell post-hoc test is used for multiple comparisons after conducting an ANOVA when the assumptions of equal variances (homogeneity of variances) or equal sample sizes are violated. This test identified statistically significant differences between all possible pairs of groups after an ANOVA revealed an overall significant difference. It also provided confidence intervals for the mean differences observed between groups. This method of analysis was selected because it does not require normal or equivalent variances of data and maintains accurate control of Type I error rate (false positives) even with unequal sample sizes.

5. Results and Discussion

To understand how students' perceptions of virtual lab experiences vary or are the same as a function of racial and ethnicity sociocultural identities, a quantitative data analysis method was performed. A total of 304 students participated in the study. Incomplete surveys were removed from the data sample, resulting in a total of 227 completed survey responses included in this analysis. The demographics (sociocultural characteristics, i.e., inputs) of students from the mechanical and aerospace undergraduate engineering course are provided in Table 3 and Table 4. The majority of the students are white and Asian, i.e., representing 37% and 31%, respectively. Students designated are marginalized in engineering, i.e., African American/Black and LatinX, represent 7% and ~12%, respectively. Finally, students of Middle Eastern and North African and two or more races represent 5% and ~2%, respectively. Due to the racial and ethnic diversity of the student participants, comprehensive impressions of laboratory experiences for engineering labs of this type (i.e., synchronous, and interactive) may be examined for understanding salient measures that may inform personalized models for evaluation in the future. After participating in the theoretical review lecture, students were asked to complete a pre-lab test that was designed to encourage students to review concepts prior to engaging in the lab.

To answer the research questions for this project, the SPVEL pre-lab and post-lab survey was distributed to students, and the averaged and standard deviation of the student responses to the questions from the SPVEL are provided in Table 1 and Table 2. An overview of the results of the pre-lab test and the post-lab laboratory report grades are provided in Table 5.

Table 3. Racial and ethnic demographics of the diverse student population that participated in the research study (IEO inputs).

Student Ethnicity	Number N	% of Students
White (Non-Latino, Not Hispanic)	85	37.4
Black or African American (Non-Latino, Not Hispanic)	16	7.0
Asians	71	31.3
White-Latino (Hispanic)	19	8.4
Black or African American (Latino, Hispanic)	2	0.9
LatinX (Latin American origin)	8	3.5
Middle Eastern/North African	12	5.3
Two or more races	4	1.8
Prefer not to answer	10	4.4
Total	**227 active participants**	100%

Table 4. Self-identified gender demographics of the student population that participated in the research study (IEO inputs).

Gender	Frequency	% of Students
Male	183	80.6
Female	37	16.3
Others/Prefer not to answer	7	3.1
Total	227	100

Table 5. Pre-lab quiz and post lab laboratory report grades. Means for populations that represent five or less are not reported in this table to maintain confidentiality of the student participants in the study.

Student Ethnicity	Grades mean (M) and Standard Deviation (STDEV)	
	LabView Pre-Lab Quiz Grade, out of 5 pts. M + STDEV	**LabView Report Grade out of 100 pts. M + STDEV**
White (Non-Latino, Not Hispanic)	4.72	75.48
Black or African American (Non-Latino, Not Hispanic)	5.00	71.11
Asians	4.71	74.31
White-Latino (Hispanic)	4.42	70.29
Black or African American (Latino, Hispanic)	5.00	95.00
LatinX (Latin American origin)	5.00	85.00
Middle Eastern/North African	4.75	80.75
Two or more races	-	-
Prefer not to answer	5.00	88.50

5.1. Test for Normality

To determine whether parametric or non-parametric statistics should be used, normality tests were performed on the collected Likert scale data from SPVEL instrument. All twenty-six variables provided a p-value of less than 0.001 for Shapiro-Wilk test for Normality, signifying the non-normal distribution of data and supporting the use of non-parametric statistics for further analysis.

5.2. Test of Homogeneity of Variance

Table 6: Results from the Homogeneity test of variance. Only questions where significance values were determined are provided in this table.

Item	Category of Question and responses	p-value	Theoretical Model
Prior virtual lab experience. Possible Choices: 0 Classes (0), 1 – 2 Classes (1), 3+ or more classes (2)			
Q1	Have you ever engaged in a virtual lab in high school?	<0.001	**IEO**
Self-Identification with the Engineering Profession- Likert Scale of 1 to 5. Possible choices: Strongly Agree (5), Somewhat Agree (4), Neither Agree nor Disagree (3), Somewhat Disagree (2), Strongly Disagree (1)			
Q14	Being an engineer is an important part of my self-image.	0.01	**ERI**
Student Perceptions of VL Experience.			
Q17	I could follow the steps in the lab.	0.05	**TAM+**
Q20	Class ran smoothly with no technical glitches.	0.018	
LabView virtual laboratory (VL) interactions and visual experiences.			
Q25	I was able to ask the TA questions in the virtual chat.	0.001	**TAM+**

Levene's test of Equality of Variances was used to assess the homogeneity of variance between groups. The null hypothesis was that the sample sizes between groups have equal variances between them. If the test produces a non-significant p-value then the test groups have equal sample sizes (equal variance between them). However, the null hypothesis is rejected if the p-value is significant, i.e., there are variances within sample sizes within groups. In this case, the p-values were less than 0.05 and hence significant for several questions from the SPVEL as described below.

Based on the findings, there is evidence that there is variance of sample sizes within the groups and if the ANOVA test is used to examine variances among groups, a post-hoc test such as Games-Howell should also be conducted simultaneously. The Games-Howell procedure is a non-parametric analysis that considers the instances when the Homogeneity of Variance is violated but still allows for the interpretation of statistical significances in the data.

5.3. ANOVA and Games-Howell: Examination of Variance of Race/Ethnicity Groups

For the test of ANOVA, the F statistic was found to be statistically significant between groups for the following questions, where the p-value (sig.) was less than 0.05. The questions where significant differences in population are listed below in **Error! Reference source not found.** and Table 7, where the ANOVA results indicate that there is a least one pair of groups that differ (i.e., have variance in the mean response). However, the ANOVA does not pinpoint which pairs of groups differ therefore, the Games-Howell post-hoc tests were performed to analyze the difference of responses between the individual groups.

The Games-Howell post-hoc test requires that each group must include a minimum six responses to make robust predictions of statistical significance between groups even if there are variances within the group sizes. Hence, for this study, groups that had less than 6 participants, were removed. Thus, students who self-identified at Black LatinX (N = 2) and two or more races (N = 4) were removed from this component of the study. Based on the Games-Howell approach, the questions where there was variance between groups are provided below. It is important to note that some of the variables that indicate statistical variance have changed since two race/ethnic groups were removed for the Game-Howell approach. The questions that presented significant differences between group pairs are listed in Table 7.

According to the Games-Howell approach, the responses to Question 1 (Q1) show statistically significant differences between White, Non-Latino (Not Hispanic) and Black or African American (Non-Latino/Not Hispanic) (p-value = 0.054) and between White, Non-Latino and LatinX students (p-value = 0.054). Also, there are statistically significant differences between Black or African American (Non-Latino, Not Hispanic) and Asian (p-value = 0.019). In addition, there are statistically significant differences between LatinX and Asian (p-value = 0.019). Given that the response for the question in terms of Likert scale was 0 for "*No prior VL experience in high school,"* and 1 for some experience, one can see from the image in Figure 2 that White (Non-Latino, not Hispanic) and Asians have more experience with Virtual labs from High school compared to that of Black or African American (Non-Latino, Not Hispanic), White, Latino (Hispanic) and LatinX students. Since the number of responses from the Black or African American (Latino/Hispanic) was less than 6, results were excluded for their case.

Table 7. An overview of the questions with variance according to the Game-Howel approach are provided along with the theoretical framework.

Item	Category of Question and responses	Theoretical Model
Prior virtual lab experience. Possible Choices: 0 Classes (0), 1 – 2 Classes (1), 3+ or more classes (2)		
Q1	Have you ever engaged in a virtual lab in high school?	**IEO**
Perceptions of Virtual Labs. Likert Scale of 1 to 5. Possible student choices: Strongly Agree (5), Somewhat Agree (4), Neither Agree nor Disagree (3), Somewhat Disagree (2), Strongly Disagree (1)		
Q9	VLs can replace hands-on labs.	**IEO**
Self-Identification with the Engineering Profession- Likert Scale of 1 to 5. Possible choices: Strongly Agree (5), Somewhat Agree (4), Neither Agree nor Disagree (3), Somewhat Disagree (2), Strongly Disagree (1)		
Q14	My friends see me as an engineer.	**ERI**
LabView virtual laboratory (VL) interactions and visual experiences.		
Q25	I was able to ask the TA questions in the virtual chat.	**TAM+**

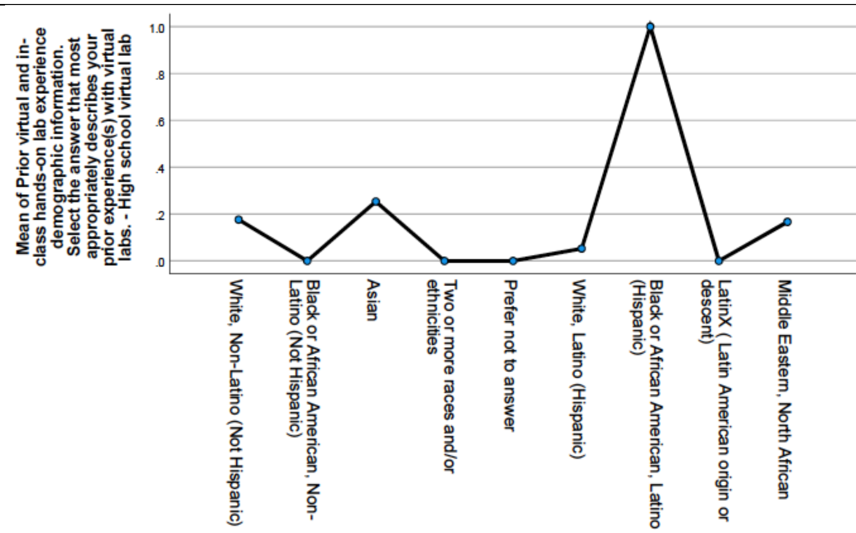

Figure 2. Plot of the means of the responses to Q1 from the SPVEL.

For the dependent variable, *Perceptions of virtual labs (VLs) - VLs can replace hands-on-labs*, Games-Howell did not find any statistically significant difference between the responses. However, from the line graph in *Figure 3*, it is observed that LatinX students scored a mean of

3.0, which was higher than other groups. Since in Likert scale, the response was set as one being at Highly Disagree and 5 being Highly Agree, any score less than 3 would mean that the group is more towards disagree rather than agree. Hence in this case, LatinX students are more confident or more open to considering VLs as a replacement for hands-on labs in the future than their peers.

Similarly, for the variable, *LabView virtual laboratory (VL) interactions and visual experiences. - I was able to ask questions in the virtual chat*, Games-Howell could not find any statistically significant difference between any groups. However, from the line chart in *Figure 4*, although almost all students affirmed that they were able to ask questions in the virtual chat, some students scored a mean of 3.0, meaning they were unsure.

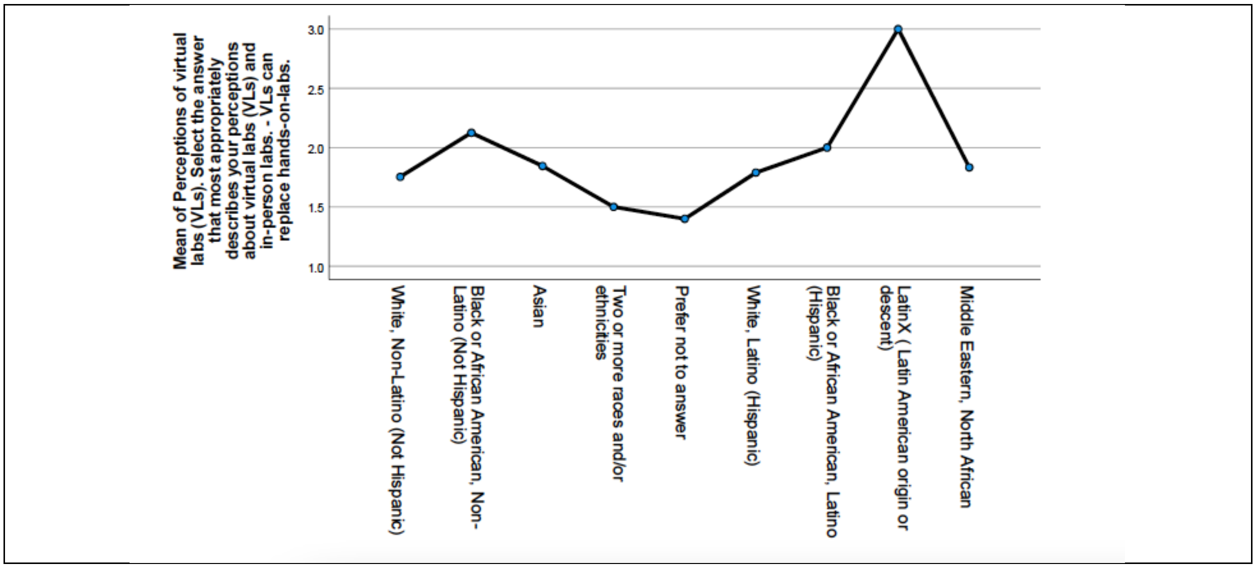

Figure 3. Plot of the means of the responses to Q9 from the SPVEL.

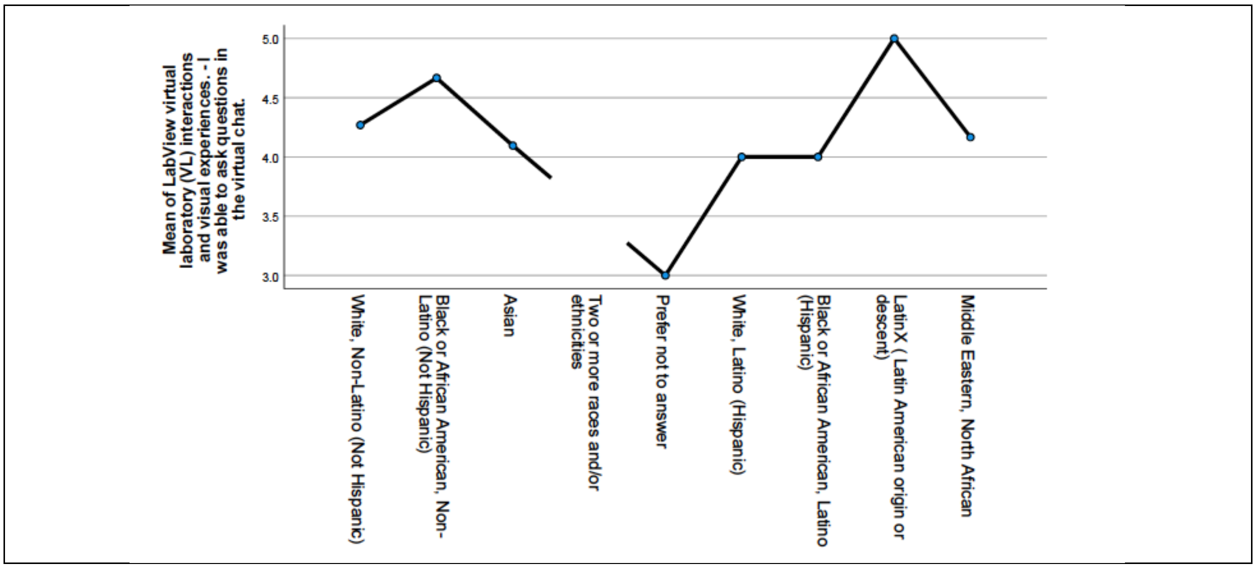

Figure 4. Plot of the means of the responses to Q14 from the SPVEL.

For the variable, *Engineering. - My friends see me as an engineer*, generally all groups (Figure 5) have rather positive outlook regarding this notion with mean response generally 4 or above, however LatinX students scored a mean on less than 3.5. This means that some of the students from the LatinX background unsure whether they are seen as engineers. Understanding this response considering requires further investigation as these students may have friends who consider or associate other aspects of their social cultural identity as having priority over other role identities, e.g., race, gender, etc. Considering the high report grades of the LatinX group, their lower engineering role identity scores may be related to a several factors. These factors may include the lack of external affirmation of their engineering identities from others due to racism, sexism, etc., which can restrict students' sense of belonging within a group[103]; or less opportunities for authentic mentorship or connection with student organizations that affirm the sociocultural and engineering identities [104, 105].

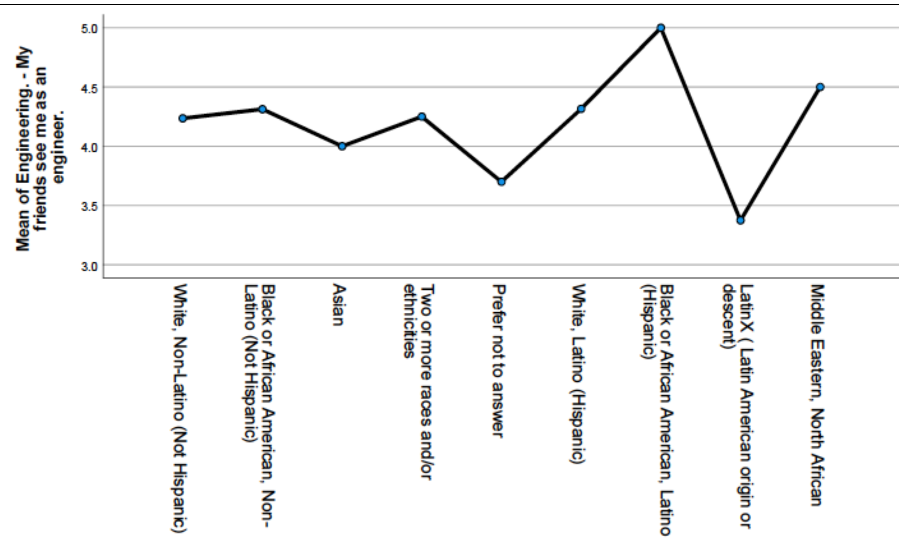

Figure 5. Plot of the means of the responses to Q25 from the SPVEL.

There was no statistical significance for either of the grades, however LatinX students scored higher than Asians and White students on their lab scores. This is interesting since the students from latter two ethnicities had more high school virtual lab experiences than Latinx students, while the LatinX students were the ones who had positive reviews regarding virtual labs being the future. While it is unclear why LatinX students who had less experience with virtual labs in high school performed better on their report grades in the virtual lab setting than their counterparts, several possibilities for this finding may exist. For example, some of the Latiné students may have had more experience with the use of mechanical equipment and tools, via jobs, personal hobbies, in-person labs, and/or extracurricular activities in high school. Another explanation for these findings could also be that students who placed higher value on the use of virtual labs derived more motivation from their use, which was evidenced in their performance on the final report. To better understand these findings, further investigation is warranted.

The grades for the Pre-lab quiz are nearly linear among the eight groups (excluding the two or more races) with white Latino (Hispanic) group scoring least with mean of 4.42. However, the disparity is more prevalent in the Lab report grades, where the White (Non-Latino, Not Hispanic) and Asians scored 75% with STDEV of 25.14 and 74.31% with STDEV of 19, respectively. This means there is a high variance of score within these groups, as well as for Black or African American (Non-Latino/Hispanic) and White Latino (Hispanic) with 71%/19.06 STDEV and 70.29%/14.78, respectively. In comparison, LatinX students had a high mean score of 85% with low STDEV of 6, as well as Middle Eastern students scoring mean of 80% with low STDEV of 11.

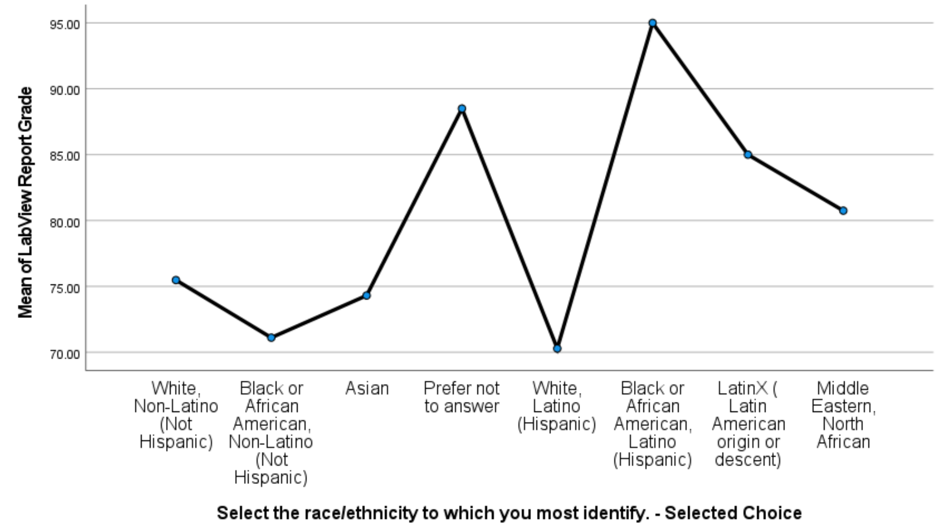

Figure 6. Plot of the means of the responses to student lab report grades.

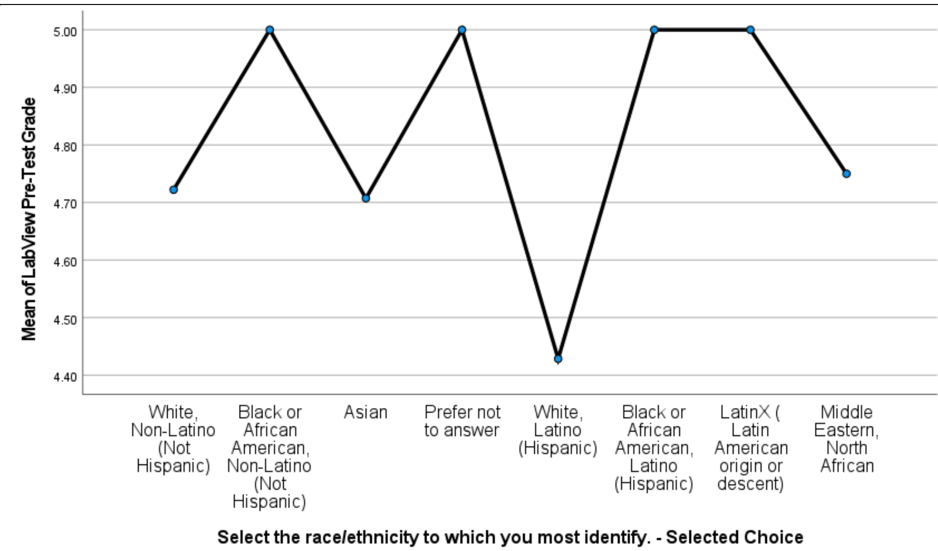

Figure 7. Plot of the means of the responses to student pre-lab quiz grades.

6. Conclusions and Future Work

This work highlights students' experiences, perceptions of value, and engagement with learning technologies when participating in a LabView virtual engineering laboratory. Using a validated assessment instrument called Students’ Perceived Value of Engineering Laboratories

(SPVEL, the authors explored how different student profile metrics can be used to inform personalized learning models of the future. The SPVEL instrument was used to collect responses from a total of 227 students during the 2020 Fall session. Considering race/ethnicity as factor, the ANOVA was performed on the dependent list of items of the SPVEL, where it was found that the p-value for the Levene's was significant, indicating variances in sample size within the race/ethnic groups. Furthermore, four of the SPVEL items showed their F statistic during ANOVA to be statistically significant between groups.

Further analysis from post hoc tests revealed that while White (Non-Latino, not Hispanic) and Asians have more experience with virtual labs from high-school, students (e.g., from LatinX backgrounds) with relatively lower experience with VL did better in on lab reports. Also, LatinX students were found to be more confident about VLs eventually being able to replace hands-on labs in the future for this class. However, they were also found to be less sure of their friends and family seeing them as engineers. It is unclear why LatinX students with less VL experience performed better in lab reports for VLs. However, possible explanations could be that use of VLs enhanced students' motivation; these students placed higher value on VLs as a learning tool, which translated to more effort in writing their lab report and/or interest in the LabView topic; or these students may have had more prior experience with mechanical equipment and tools via in-person labs, extracurricular activities, or job during high school. Additional studies will be conducted to better understand these findings and explore how they can be leveraged to enhance learning and access to all the engineering students within the department.

Although the data analyzed here was only from a single semester of a single lab course, and only factoring in ethnicity, it provided a very nuanced take which might not have been possible to find from traditional post class assessment student questionnaire. Verily, it is possible to analyze other factors of students' backgrounds to provide more information to inform personalized learning models of the future. Nevertheless, this detailed analysis already establishes SPVEL as a valuable tool for educational psychology and engineering education when analyzing digital educational tools, to understand student perception of their learning environment while considering their backgrounds.

References

[1] R. K. Scheckler, "Virtual labs: a substitute for traditional labs?," *International Journal of Developmental Biology,* vol. 47, no. 2-3, pp. 231-236, 2003.

[2] A. Spernjak and A. Sorgo, "Differences in acquired knowledge and attitudes achieved with traditional, computer-supported and virtual laboratory biology laboratory exercises," *Journal of Biological Education*, vol. 52, no. 2, pp. 206-220, 2018.

[3] K. L. Evans, D. Yaron, and G. Leinhardt, "Learning stoichiometry: a comparison of text and multimedia formats," *Chemistry Education Research and Practice*, vol. 9, no. 3, pp. 208-218, 2008.

[4] K. Achuthan and S. S. Murali, "A Comparative Study of Educational Laboratories from Cost & Learning Effectiveness Perspective," in *Software Engineering in Intelligent Systems*, Cham, R. Silhavy, R. Senkerik, Z. K. Oplatkova, Z. Prokopova, and P. Silhavy, Eds., 2015// 2015: Springer International Publishing, pp. 143-153,

[5] D. M. Adams, C. Pilegard, and R. E. Mayer, "Evaluating the Cognitive Consequences of Playing Portal for a Short Duration," *Journal of Educational Computing Research*, vol. 54, no. 2, pp. 173-195, Apr 2016.

[6] E. Ye, C. Liu, and J. A. Polack-Wahl, "Enhancing software engineering education using teaching aids in 3-D Online Virtual Worlds," in *2007 37th Annual Frontiers in Education Conference, Global Engineering : Knowledge without Borders - Opportunities without Passports*, Milwaukee, Wisconsin, 2007, vol. 1 - 4: Institute of Electrical and Electronics Engineers (IEEE), in Frontiers in Education Conference, p. 87.

[7] T. A. Philpot, R. H. Hall, N. Hubing, and R. E. Flori, "Using games to teach statics calculation procedures: Application and assessment," (in English), *Comput. Appl. Eng. Educ.*, Article vol. 13, no. 3, pp. 222-232, Oct 2005.

[8] V. Potkonjak, M. Gardner, V. Callaghan, P. Mattila, C. Guetl, V. M. Petrovic, and K. Jovanovic, "Virtual laboratories for education in science, technology, and engineering: A review," *Computers & Education*, vol. 95, pp. 309-327, Apr 2016.

[9] M. Pantoja, "Designing a New Video Game App as an aid for Introduction to Programming classes that use C Programming Language," in *3rd International Conference on Higher Education Advance, Head'17* Universitat Politecnica de Valencia, Valencia, 2017, pp. 10-16.

[10] T. C. N. Graham and W. Roberts, "Toward quality-driven development of 3D computer games," in *Interactive Systems: Design, Specification, and Verification*, vol. 4323, G. Doherty and A. Blandford Eds., (Lecture Notes in Computer Science, 2007.

[11] E. M. Jimenez-Hernandez, H. Oktaba, F. D. B. Arceo, M. Piattini, A. M. Revillagigedo-Tulais, and S. V. Flores-Zarco, "Methodology to construct educational video games in software engineering," *2016 Fourth International Conference in Software Engineering Research and Innovation - Conisoft 2016*, pp. 110-114, 2016.

[12] J. N. Long, L. S. Young, and Asee, "Multiplayer On-Line Role Playing Game Style Grading in a Project Based Software Engineering Technology Capstone Sequence," in *American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Vancouver, BC, 2011, in ASEE Annual Conference & Exposition, pp. 22.1091.1 - 22.1091.20, [Online]. Available: https://peer.asee.org/18922

[13] H. A. Mitre-Hernandez, C. Lara-Alvarez, M. Gonzalez-Salazar, and D. Martin, "Decreasing Rework in Video Games Development from a Software Engineering Perspective," in *Trends and Applications in Software Engineering*, vol. 405, J. Mejia, M.

Munoz, A. Rocha, and J. CalvoManzano Eds., (Advances in Intelligent Systems and Computing, 2016, pp. 295-304.
[14] E. Murphy-Hill, T. Zimmermann, and N. Nagappan, "Cowboys, Ankle Sprains, and Keepers of Quality: How Is Video Game Development Different from Software Development?," presented at the 36th International Conference on Software Engineering (Icse 2014), Hyderabad, India, 2014.
[15] J. Musil, A. Schweda, D. Winkler, and S. Biffl, "Improving Video Game Development: Facilitating Heterogeneous Team Collaboration through Flexible Software Processes," in *Systems, Software and Services Process Improvement*, vol. 99, A. Riel, R. Oconnor, S. Tichkiewitch, and R. Messnarz Eds., (Communications in Computer and Information Science, 2010, pp. 83-94.
[16] E. Ozcelik, N. E. Cagiltay, and N. S. Ozcelik, "The effect of uncertainty on learning in game-like environments," *Computers & Education,* vol. 67, pp. 12-20, Sep 2013.
[17] J. N. Sutherland, *Towards a software engineering methodology for video games development: object orientation as an approach for specification analysis* (Vsmm 2000: 6th International Conference on Virtual Systems and Multimedia). 2000, pp. 569-576.
[18] J. Whitehead and C. Lewis, "Workshop on Games and Software Engineering (GAS 2011)," presented at the 2011 33rd International Conference on Software Engineering (ICSE), Honolulu, HI, USA, 2011.
[19] R. Morsi and S. Mull, "Digital Lockdown: A 3D Adventure Game for Engineering Education," in *Frontiers in Education Conference,* (Frontiers in Education Conference, 2015, pp. 316-319.
[20] S. Smith and S. Chan, "Collaborative and Competitive Video Games for Teaching Computing in Higher Education," *Journal of Science Education and Technology,* vol. 26, no. 4, pp. 438-457, Aug 2017.
[21] M. J. Callaghan, K. McCusker, J. L. Losada, J. Harkin, and S. Wilson, "Using Game-Based Learning in Virtual Worlds to Teach Electronic and Electrical Engineering," *Ieee Transactions on Industrial Informatics,* vol. 9, no. 1, pp. 575-584, Feb 2013.
[22] Y. Z. Chang, E. S. Aziz, Z. Zhang, M. S. Zhang, and S. K. Esche, "Evaluation of a video game adaptation for mechanical engineering educational laboratories," in *2016 IEEE Frontiers in Education Conference*, (Frontiers in Education Conference, 2016.
[23] R. Joiner, J. Iacovides, M. Owen, C. Gavin, S. Clibbery, J. Darling, and B. Drew, "Digital Games, Gender and Learning in Engineering: Do Females Benefit as Much as Males?," *Journal of Science Education and Technology,* vol. 20, no. 2, p. page 182, Apr 2011.
[24] P. Pejic, S. Krasic, H. Krstic, M. Dragovic, and Y. Akbiyik, "3D virtual modelling of existing objects by terrestrial photogrametric methods - Case study of Barutana," *Tehnicki Vjesnik-Technical Gazette*, vol. 24, pp. 233-239, May 2017.
[25] A. A. Choudhury and J. Rodriguez, "A New Curriculum in Fluid Mechanics for the Millennial Generation," *Ieee Revista Iberoamericana De Tecnologias Del Aprendizaje-Ieee Rita,* vol. 12, no. 1, pp. 48-51, Feb 2017.
[26] B. D. Coller, "Work in Progress - A Video Game for Teaching Dynamics," in *2011 Frontiers in Education Conference*, (Frontiers in Education Conference, 2011.
[27] B. D. Coller, "A Video Game for Teaching Dynamic Systems & Control to Mechanical Engineering Undergraduates," in *Proceedings of the 2010 American Control Conference*, Baltimore, MD, USA, 2010, in Proceedings of the American Control Conference, pp. 390-395.

[28] B. D. Coller and M. J. Scott, "Effectiveness of using a video game to teach a course in mechanical engineering," *Computers & Education,* vol. 53, no. 3, pp. 900-912, Nov 2009.

[29] B. D. Coller and D. J. Shernoff, "Video Game-Based Education in Mechanical Engineering: A Look at Student Engagement," *International Journal of Engineering Education,* vol. 25, no. 2, pp. 308-317, 2009.

[30] C. G. Panagiotopoulos and G. D. Manolis, "A web-based educational software for structural dynamics," *Comput. Appl. Eng. Educ.,* vol. 24, no. 4, pp. 599-614, Jul 2016.

[31] J. F. O. Granjo and M. G. Rasteiro, "LABVIRTUAL-A platform for the teaching of chemical engineering: The use of interactive videos," *Comput. Appl. Eng. Educ.,* vol. 26, no. 5, pp. 1668-1676, Sep 2018.

[32] S. Ramos, E. P. Pimentel, M. D. B. Marietto, and W. T. Botelho, "Hands-on and Virtual Laboratories to Undergraduate Chemistry Education: Toward a Pedagogical Integration," presented at the 2016 IEEE Frontiers in Education Conference, Erie, PA, 2016.

[33] Z. Kosmadoudi, T. Lim, J. Ritchie, S. Louchart, Y. Liu, and R. Sung, "Engineering design using game-enhanced CAD: The potential to augment the user experience with game elements," *Computer-Aided Design,* vol. 45, no. 3, pp. 777-795, Mar 2013.

[34] E. Ozkop, "A Virtual Electric Power Transmission Line Lab," *International Journal of Engineering Education,* vol. 32, no. 5, pp. 2240-2249, 2016.

[35] N. A. Yalcin and F. Vatansever, "A Web-Based Virtual Power Electronics Laboratory," *Comput. Appl. Eng. Educ.,* vol. 24, no. 1, pp. 71-78, Jan 2016.

[36] A. Cardoso, D. Osorio, J. Leitao, V. Sousa, V. Graveto, and C. Teixeira, "Demonstration of modeling and simulation of physiological processes using a remote lab," in *Proceedings of 2015 3rd Experiment at International Conference*, (Experiment at International Conference, 2015, pp. 103.

[37] D. Romberg, J. W. Dyer, and E. J. Berbari, "Cell2ECG: A virtual laboratory to simulate cardiac electrograms," in *2013 IEEE Frontiers in Education Conference*, (Frontiers in Education Conference, 2013.

[38] M. Okutsu, D. DeLaurentis, S. Brophy, and J. Lambert, "Teaching an aerospace engineering design course via virtual worlds: A comparative assessment of learning outcomes," *Computers & Education,* vol. 60, no. 1, pp. 288-298, Jan 2013.

[39] Y. E. Cherner, M. M. Kuklja, M. J. Cima, A. I. Rusakov, A. S. Sigov, and C. Settens, "The Use of Web-based Virtual X-Ray Diffraction Laboratory for Teaching Materials Science and Engineering," *Mrs Advances,* vol. 2, no. 31-32, pp. 1687-1692, 2017.

[40] M. M. Ratamun and K. Osman, "THE EFFECTIVENESS OF VIRTUAL LAB COMPARED TO PHYSICAL LAB IN THE MASTERY OF SCIENCE PROCESS SKILLS FOR CHEMISTRY EXPERIMENT," *Problems of Education in the 21st Century,* vol. 76, no. 4, pp. 544-560, 2018.

[41] S. Bhattacharyya, "Examining Staged Enhancements for Thermodynamic Cycles to Improve Performance using an Intelligent Instruction Software," *International Journal of Engineering Education,* vol. 16, no. 4, pp. 340-350, 2000.

[42] D. Sotelo, C. Sotelo, R. A. Ramirez-Mendoza, E. A. López-Guajardo, D. Navarro-Duran, E. Niño-Juárez, and A. Vargas-Martinez, "Lab-Tec@Home: A Cost-Effective Kit for Online Control Engineering Education," *Electronics,* vol. 11, no. 6, Mar 2022, Art no. 907.

[43] S. Chatterjee, "Revolutionizing science education through virtual laboratories," *Advances in Science Education*, vol. 118, 2021.
[44] J. Ndunagu, K. Ukhurebor, and A. Adeshina, *Virtual Laboratories for STEM in Nigerian Higher*. 2023.
[45] K. Cook-Chennault, D. Cummings, M. Anthony, T. Balar, L. Izzell, S. Boone, and C. Watson, "What Informal Learning Programs Teach Us About Adaptation to Contactless and Remote Learning Environments," in *2021 IEEE Frontiers in Education Conference (FIE)*, 2021: IEEE, pp. 1-8,
[46] "Building Equity in STEM Education: Strategies for Ensuring Access for All Students," vol. 2024, ed. 561 Windsor St., Somerville, MA, 02143: Labster, 2022.
[47] V. Potkonjak, M. Gardner, V. Callaghan, P. Mattila, C. Guetl, V. M. Petrović, and K. Jovanović, "Virtual laboratories for education in science, technology, and engineering: A review," *Computers & Education*, vol. 95, pp. 309-327, 2016/04/01/ 2016.
[48] K. Cook-Chennault and A. Farooq, "A Validated Assessment Tool: Students' Perceived Value of Engineering Laboratories in a Virtual Environment," *International Journal of Engineering Education*, vol. 39, no. 4, pp. 860-876, 2023.
[49] J. Qadir and A. Al-Fuqaha, "A Student Primer on How to Thrive in Engineering Education during and beyond COVID-19," *Education Sciences*, vol. 10, no. 9, Sep 2020, Art no. 236.
[50] E. A. Vogels, "Some digital divides persist between rural, urban and suburban America," in *Rural Residents & Tech*, ed. Washington, DC: Pew Research Center, 2021.
[51] "Free and Low-Cost Internet Options." NYC Public Schools. (accessed February 6, 2024).
[52] "Project 10Million - Access to the internet is access to opportunity." T-Mobile. (accessed February 6, 2024).
[53] "Free WiFi - Jersey City Public Libraries." https://www.jclibrary.org/services/free-wifi/ (accessed February 6, 2024).
[54] "Computers, Internet and Wireless Access." https://www.nypl.org/help/computers-internet-and-wireless-access (accessed February 6, 2024).
[55] "Free and Lower-Cost Internet." South Carolina Department of Education. https://ed.sc.gov/districts-schools/shared-services/free-and-lower-cost-internet/ (accessed February 6, 2024).
[56] "NAE Grand Challenges for Engineering." Nagtional Academy of Engineering. https://www.engineeringchallenges.org/ (accessed February 6, 2024).
[57] B. S. Bloom, "The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring," *Educational researcher*, vol. 13, no. 6, pp. 4-16, 1984.
[58] J. Dewey, *Democracy and education : an introduction to the philosophy of education*. New York (State): The Macmillan company, 1916, 1916.
[59] B. F. Skinner, "Teaching Machines," *Science (American Association for the Advancement of Science)*, vol. 128, no. 3330, pp. 969-977, 1958.
[60] M. Montessori, *The absorbent mind*. New York: Dell, 1967.
[61] J. F. Pane, E. D. Steiner, M. D. Baird, and L. S. Hamilton, "Continued Progress: Promising Evidence on Personalized Learning," RAND Corporation, 2015.

[62] G. Carey and C. Grant, "Teacher and student perspectives on one-to-one pedagogy: practices and possibilities," *British Journal of Music Education*, vol. 32, no. 1, pp. 5-22, 2015.
[63] A. J. Javier, "Neurodiverse Architecture: Reframing Early Childhood Learning Environment," Carleton University, 2023.
[64] C. Baggio, "Language teaching accessibility of students with specific language needs: a Montessori approach to reading and writing," 2017.
[65] J. Asbell-Clarke, *Reaching and Teaching Neurodivergent Learners in STEM: Strategies for Embracing Uniquely Talented Problem Solvers*. Taylor & Francis, 2023.
[66] M. L. Bernacki, M. J. Greene, and N. G. Lobczowski, "A Systematic Review of Research on Personalized Learning: Personalized by Whom, to What, How, and for What Purpose(s)?," *Educational psychology review*, vol. 33, no. 4, pp. 1675-1715, 2021.
[67] P. E. France, *Reclaiming personalized learning : A pedagogy for restoring equity and humanity in our classrooms*, Second edition. ed. Thousand Oaks: Corwin, 2022.
[68] C. Pipkin, "Winning in the Classroom with your Personalized Learning Playbook," in *EdSurge*: International Society for Technology in Education (ISTE), 2015, ch. Five Key Elements of Personalized Learning.
[69] A. Shemshack and J. M. Spector, "A systematic literature review of personalized learning terms," *Smart learning environments*, vol. 7, no. 1, pp. 1-20, 2020.
[70] K. Cook-Chennault and A. Farooq, "Student perceived value of engineering labs: a lab assessment instrument," *International Journal of Evaluation and Research in Education*, vol. 13, no. 4, 2024.
[71] R. L. Waltz, "The 21st-century andragogue: The search for meaning and mission in the adult classroom," School of Education & Behavioral Studies, ProQuest Dissertations Publishing, Azusa Pacific University, 2004.
[72] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *Mis Quarterly*, vol. 13, no. 3, pp. 319-340, Sep 1989.
[73] F. D. Davis, "User acceptance of information technology: system characteristics, user perceptions and behavioral impacts," *International Journal of Man-Machine Studies*, vol. 38, pp. 475-487, 1993.
[74] V. T. Nguyen, R. Hite, and T. Dang, "Learners' Technological Acceptance of VR Content Development: A Sequential 3-Part Use Case Study of Diverse Post-Secondary Students," *International Journal of Semantic Computing*, vol. 13, no. 3, pp. 343-366, Sep 2019.
[75] M. M. Raikar, P. Desai, M. Vijayalakshmi, and P. Narayankar, *Augmenting Cloud concepts learning with Open source software environment* (2018 International Conference on Advances in Computing, Communications and Informatics). 2018, pp. 1405-1411.
[76] R. Estriegana, J. A. Medina-Merodio, and R. Barchino, "Student acceptance of virtual laboratory and practical work: An extension of the technology acceptance model," *Computers & Education*, vol. 135, pp. 1-14, Jul 2019.
[77] K. Cook-Chennault, I. V. Alarcon, and G. Jacob, "Usefulness of Digital Serious Games in Engineering for Diverse Undergraduate Students," *Education Sciences*, vol. 12, no. 1, Jan 2022, Art no. 27.
[78] K. Cook-Chennault and I. Villanueva, "An initial exploration of the perspectives and experiences of diverse learners' acceptance of online educational engineering games as learning tools in the classroom," in *49th IEEE Frontiers in Education Conference (FIE)*,

Univ Cincinnati, Cincinnati, OH, Oct 16-19 2019, in Frontiers in Education Conference, 2019.
[79] K. Cook-Chennault and I. Villanueva, "Exploring perspectives and experiences of diverse learners' acceptance of online educational engineering games as learning tools in the classroom," in *IEEE Frontiers in Education Conference (FIE)*, Uppsala, SWEDEN, Oct 21-24 2020, in Frontiers in Education Conference, 2020.
[80] A. W. Astin, "Student involvement: A developmental theory for higher education (Reprinted from Journal of College Student Development, July, 1984)," *Journal of College Student Development*, vol. 40, no. 5, pp. 518-529, Sep-Oct 1999.
[81] M. M. Kim and E. L. Kutscher, "College Students with Disabilities: Factors Influencing Growth in Academic Ability and Confidence," *Research in Higher Education*, vol. 62, pp. 309 - 331, 2021.
[82] L. D. Goegan and L. M. Daniels, "Students with LD at Postsecondary: Supporting Success and the Role of Student Characteristics and Integration," *Learning Disabilities Research & Practice*, vol. 35, no. 1, pp. 45-56, Feb 2020.
[83] L. D. Goegan and L. M. Daniels, "Academic Success for Students in Postsecondary Education: The Role of Student Characteristics and Integration," *Journal of College Student Retention-Research Theory & Practice*, 2019, Art no. Unsp 1521025119866689.
[84] A. N. Bryant, "Changes in attitudes toward women's roles: Predicting gender-role traditionalism among college students," *Sex Roles*, vol. 48, no. 3-4, pp. 131-142, Feb 2003.
[85] L. P. Luu and A. G. Inman, "Feminist identity and program characteristics in the development of trainees' social advocacy," *Counselling Psychology Quarterly*, vol. 31, no. 1, pp. 1-24, 2018.
[86] P. D. Zhang and W. L. Smith, "From High School to College: The Transition Experiences of Black and White Students," *Journal of Black Studies*, vol. 42, no. 5, pp. 828-845, Jul 2011.
[87] A. Godwin and A. Kirn, "Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives," *Journal of Engineering Education*, vol. 109, no. 3, pp. 362-383, Jul 2020.
[88] A. Godwin, "The Development of a Measure of Engineering Identity," presented at the 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, 2016, 10.18260/p.26122.
[89] M. M. Bakhtin, M. Holquist, and C. Emerson, *The Dialogic Imagination: Four Essays*. University of Texas Press, 2010.
[90] H. B. Carlone and A. Johnson, "Understanding the science experiences of successful women of color: Science identity as an analytic lens," *Journal of Research in Science Teaching*, vol. 44, no. 8, pp. 1187-1218, Oct 2007.
[91] A. Godwin, L. Klotz, Z. Hazari, and G. Potvin, "Sustainability Goals of Students Underrepresented in Engineering: An Intersectional Study," *International Journal of Engineering Education*, vol. 32, no. 4, pp. 1742-1748, 2016.
[92] S. Jarvela and K. A. Renninger, *Designing for Learning: Interest, Motivation, and Engagement* (Cambridge Handbook of the Learning Sciences, 2nd Edition). 2014, pp. 668-685.

[93] X. L. Wang, "Why Students Choose STEM Majors: Motivation, High School Learning, and Postsecondary Context of Support," *American Educational Research Journal*, vol. 50, no. 5, pp. 1081-1121, Oct 2013.

[94] O. Pierrakos, T. K. Beam, H. Watson, E. Thompson, and R. Anderson, "Gender Differences in Freshman Engineering Students' Identification with Engineering," in *2010 IEEE Frontiers in Education Conference (FIE)*, Arlington, VA, USA, 2010, in Frontiers in Education Conference, pp. S3C-1-S3C-6.

[95] J. W. Creswell and V. L. Plano Clark, *Designing and Conducting Mixed Methods Research*. Thousand Oaks, California: Sage Publications, Inc, 2018, p. 492.

[96] "The Carnegie Classification of Institutions of High Education," in "2018 Update - Facts & Figures," Indiana University, School of Education, Bloomington, IN, 2019. Accessed: November 6, 2023. [Online]. Available: https://carnegieclassifications.acenet.edu/

[97] H. Levene, "Robust tests for equality of variances " in *Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling*, I. Olkin Ed. Palo Alto, CA: Stanford University Press, 1960.

[98] C. A. Mertler, R. A. Vannatta, and K. N. LaVenia, *Advanced and multivariate statistical methods: Practical application and interpretation*. Routledge, 2021.

[99] C. Sindermann, R. Riedl, and C. Montag, "Investigating the Relationship between Personality and Technology Acceptance with a Focus on the Smartphone from a Gender Perspective: Results of an Exploratory Survey Study," *Future Internet*, vol. 12, no. 7, p. 110, 2020.

[100] C. Walkington and M. L. Bernacki, "Appraising research on personalized learning: Definitions, theoretical alignment, advancements, and future directions," vol. 52, ed: Taylor & Francis, 2020, pp. 235-252.

[101] M. Bulger, "Personalized learning: The conversations we're not having," *Data and Society*, vol. 22, no. 1, pp. 1-29, 2016.

[102] W. P. Vogt and R. B. Johnson, *The SAGE dictionary of statistics & methodology: A nontechnical guide for the social sciences*. Sage publications, 2015.

[103] P. O. Garriott, A. Carrero Pinedo, H. K. Hunt, R. L. Navarro, L. Y. Flores, C. D. Desjarlais, D. Diaz, J. Brionez, B. H. Lee, E. Ayala, L. D. Martinez, X. Hu, M. K. Smith, H. N. Suh, and G. G. McGillen, "How Latiné engineering students resist White male engineering culture: A multi-institution analysis of academic engagement," *Journal of Engineering Education*, vol. 112, no. 3, pp. 695-718, 2023.

[104] S. L. Rodriguez, E. E. Doran, M. Sissel, and N. Estes, "Becoming La Ingeniera: Examining the Engineering Identity Development of Undergraduate Latina Students," *Journal of Latinos and Education*, vol. 21, no. 2, pp. 181-200, 2022/03/15 2022.

[105] R. A. Revelo and L. D. Baber, "Engineering resistors: Engineering Latina/o students and emerging resistant capital," *Journal of Hispanic Higher Education*, vol. 17, no. 3, pp. 249-269, 2018.