A Law of Diminishing Returns: Quantifying Online Accessibility for Engineering Students With Disabilities in the Wake of the COVID-19 Pandemic

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***Abstract*—*Contribution:* This article identifies the barriers students with disabilities have faced when accessing online undergraduate engineering education since the initial onset of the COVID-19 pandemic. This research addresses the need for greater research that explores the digital equity gap that widens as schools continue to use virtual and/or distance learning.**

***Background:* Poor accessibility standards, a lack of administrative support, and numerous other barriers have contributed to the ever-present digital equity gap for students with disabilities. Previous research has shown that the implementation of universal design for learning (UDL) principles can have a positive impact on in-classroom learning, particularly for historically marginalized students. Related research on UDL has been primarily focused on nonengineering, nondisabled, and in-person teaching contexts.**

***Research Questions:* What barriers do engineering students with disabilities face in an online learning environment? What affects disabled students' perceived value of learning in their online classes?**

***Methodology:* A fixed-item survey was developed to capture the experiences of students with disabilities in engineering who participated in online learning at four-year colleges and universities across the United States.**

***Findings:* The results of this study have revealed a correlation between accessibility barriers in online undergraduate engineering learning environments and UDL principles.**

***Index Terms*—COVID, distance learning, equity, inferential statistics, students with disabilities.**

I. Introduction

THERE is well-documented discrimination against people with disabilities regarding the use of technology in education. This discrimination creates digital inequities [1], which have continued to widen as schools have increasingly moved to virtual or distance learning following the initial COVID-19 disruption. More than two-thirds of classroom teaching globally are now taught virtually, prompting interest from educators to use the shift to expand flexible learning options (e.g., hybrid and distance) [2]. This has created an equity gap as accessibility and technical infrastructure were not prerequisites during the initial shift to virtual learning [2]. Ever-present digital inequities and the expansion of virtual classes suggest an urgent need to address existing barriers for students with disabilities in higher education to improve accessibility and inspect the impact these challenges have on perceived value of education.

This research uses universal design for learning (UDL) to better understand students with disabilities' accessibility barriers in undergraduate and graduate engineering education. The following paper aims to address the following research questions: 1) What accessibility barriers do engineering students with disabilities most face in an online learning environment? and 2) What affects disabled students' perceived value of learning in their online classes? Findings are intended to inform accessibility improvements and considerations to online learning for all students.

II. Background

Previous research has been done to address digital accessibility barriers for students with disabilities [3], [4]. The following subsections break down the work that has been done to address inequities in higher education for students with disabilities and the current state of online learning. A review of the literature in these areas is used to help contextualize the barriers and course difficulties students with disabilities may face following the initial COVID-19 disruption.

A. Students With Disabilities Students in Engineering Higher Education

Engineering has been criticized for having diversity, equity, and inclusivity problems [5]. Students with disabilities face a unique set of barriers before, during, and after entering higher education. Before college, students with disabilities are rarely encouraged to identify possible post-secondary institutions and programs of interest [6]. According to Martin et al. [7], students with disabilities often leave high school with lower college aspirations and are discouraged from taking any engineering-related courses.

Students with disabilities who do choose to pursue higher education face an additional slew of challenges upon entry (e.g., trouble accessing and/or receiving accommodations,

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balancing workload, and managing mental health) [8], [9], [10], [11]. This has resulted in 25% of students with disabilities dropping out after their first year and 35% by the end of their second year [12]. According to Getzel and Thoma [13], "adjusting to a college environment presents challenges for all students; however, for students with disabilities, the responsibility of managing their accommodations along with their academic course work presents a set of challenges unique to these students" (p. 77).

One contributing factor to these unique challenges is digital inequities, resulting from poor accessibility standards [14]. These inequities create barriers for people with disabilities, especially those planning to pursue an engineering degree and a future STEM career [1]. This reflects the low unemployment rate for scientists and engineers with disabilities, which is greater than that of the entire U.S. labor force [15], [16]. Support structures for people with disabilities remain ineffective, as those with disabilities must navigate physical, cultural, and bureaucratic barriers to access the resources necessary for success [9], [11]. Students with disabilities have a 29% completion rate for four-year universities, with no significant differences by race, ethnicity, gender, household income, or disability type [17].

B. Students With Disabilities in Online Courses

Virtual and distance learning have been available teaching modalities for decades. The COVID-19 pandemic insighted increased use, availability, and necessity for such modalities [18], [19]. Today's instructors regularly engage in some form of electronic learning ranging from fully virtual classes to digital technologies (e.g., simulations, digital presentations, videos, or online textbooks) [20], [21]. Many institutions do not have policies in place for virtual accessibility standards, despite the virtual learning demand [22]. This extends beyond interest from instructors to make their online content more accessible because many institutions also do not have e-learning accessibility training for faculty and staff to assist with virtual accessibility [23].

Literature shows that students with disabilities in online courses feel like they have less overall support and fewer adjustments for their disabilities than in-person classes [24], [25]. Many faculty designing virtual or hybrid courses unintentionally create access barriers that exclude students with disabilities [3], [26]. Common access barriers in online courses and e-learning include uncaptioned videos, difficult-to-read content (e.g., slide presentations, articles, and images), and disorganized course websites/learning management systems [27]. A study done by Heiman [28] revealed that nearly 50% of students with disabilities reported that they perceived their disabilities to have negatively affected their performance in an online course. Online barriers for students with disabilities go beyond academic performance because of the additional time and effort taken by students with disabilities to circumvent virtual learning obstacles. This can cascade into stress and anxiety, which results in a reduced quality of life, lower self-esteem, and strained personal relationships [29], [30]. These barriers can significantly and negatively influence students' overall learning, potentially reducing the value of their education [29].

TABLE I
UDL GUIDELINES FOR INCLUSION DESIGN [33]

Provide Multiple Means of Representation	Provide Multiple Means of Action and Expression	Provide Multiple Means of Engagement
Perception	Physical action	Recruiting interest
Language, expression, and symbols	Expression and communication	Sustaining effort and persistence
Comprehension	Executive function	Self-regulation

III. THEORETICAL FRAMEWORK

Universal design is a barrier-free design approach that originated in architecture. The approach aims to maximize design products' and built environments' usability to the widest audience possible regardless of one's age, ability, or status [31]. Design researchers, architects, and engineers developed the initial set of universal design principles to "proactively reduc[e] environmental barriers and provid[e] increased access to the physical environment" [32]. Universal design has now expanded to numerous other fields, including education.

UDL is a universal design framework created as an educational model to extend the framework for broadened access into the learning environment [33]. UDL uses three guiding principles for the design of inclusive learning: 1) providing several flexible modes for students to gather information; 2) allowing for flexible modes of student expression in acquiring knowledge; and 3) developing and retaining student interest through interactive engagement to ensure students are appropriately challenged by the material [34], [35]. The guiding principles categories of UDL were used to conceptualize barriers to access in virtual learning. This framework was also used to guide instrument and item development, data analysis, and data interpretation for this study. A table further describing these principles is displayed in Table I.

Using UDL to standardize virtual learning has been found to have positive effects on students' perceived quality of learning and overall acceptance of e-learning [36], [37]. There is a unique opportunity to create and adopt learning-based technologies using a UDL lens to prioritize students with disabilities, while also advancing the learning of nondisabled individuals.

IV. METHODS

A. Survey Design

The online accessibility for students with disabilities scale (OADS) was developed to investigate students with disabilities' experiences in online learning while identifying any subsequent digital equity gaps. Its design was informed by surveys exploring students with disabilities and online learning [8]; surveys related to UDL strategies [38]; surveys regarding perceived challenge and self-concepts [39], [40]; and a scale on control and relevance of schoolwork [41].

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The survey consists of 59 items, including 13 demographic items and 46 items capturing four major constructs tied to the research questions: 1) accommodations for virtual learning; 2) accessibility; 3) perceived course difficulty; and 4) perceived value of learning. A 4-point Likert scale was chosen in order to limit respondent neutrality based on literature regarding disproportionately large "neutral" responses to items [42], [43] and the research teams' own views that one cannot be neutral about facing oppression. The construct items were averaged before analysis for each participant so that the constructs could be treated as an averaged score. The Appendix displays the OADS' survey constructs and survey questions.

B. Role of the Researchers

The first author identifies as an engineering student with disabilities and at the time of data collection, analysis, and drafting of this document, is pursuing a doctoral degree in Engineering Education. These identities helped in understanding the experiences of those with disabilities in order to develop the OADS survey and interpreting the data with a perspective representative of the student participants. The second author identifies as an engineering faculty member and engineering education researcher who is nondisabled. We acknowledge that our held identities may introduce bias into the analysis of data. We mitigated such biases through the mixing of our identities and regularly discussing interpretations between authors during all stages of the research.

C. Initial Validity Testing

Validity evidence was collected to test the initial set of items and inform potential changes. A focus group was conducted with two engineering students with disabilities who have participated in online learning to examine the validity associated with use. Focus groups allowed the researchers to better understand the perceptions, beliefs, and values of culturally diverse groups in quantitative research [44]. Two subject matter experts with expertise in creating fixed-item surveys and/or studying students with disabilities were also recruited to provide additional validity evidence. The subject matter experts were used to determine the domain relevance and representativeness of the survey items for each construct.

Focus group participants and subject matter experts were asked to individually rate each survey item on a 5-point Likert Scale: "5" the test is extremely suitable for the given purpose, "4" the test is very suitable for that purpose, "3" the test is adequate, "2" the test is inadequate, and "1" the test is irrelevant, therefore unsuitable [45]. The focus group participants' average item rating was 4.84, with an 83.93% agreement. Items were determined to be comprehensible for the target group based on an average rating of 4.84 and 83.93% agreement from the focus group; the percent agreement is well over the 41% suggested minimum threshold [46]. The subject matter experts' average item rating was 3.11, with the lowest ratings associated with the Accessibility construct. Items were removed or modified based on the suggestions of the subject matter experts.

V. Data Collection and Analysis

A. Participants

Approximately 1500 engineering department heads, diversity office leaders, disability office leaders, and professional engineering student organization leaders from U.S. colleges and universities were contacted to distribute this online survey to their engineering students during the Spring 2022 semester. Survey respondents were entered in a raffle for $20 gift cards. A total of 1078 students responded to the survey; 450 students indicated that they were a current engineering student with disabilities. The sample of participants identifying as a current engineering student with disabilities was used for this study. Additional demographics for this sample included gender—34.5% male, 50% female, and 10.5% transgender or nonbinary (TGNC) (5% chose not to respond)—and race and ethnicity—12% Asian, 3% Black or African American, 10% Hispanic or Latino, 3% Middle Eastern or North African, 1% Native American or Alaskan Native, <1% Native Hawaiian or Pacific Islander, 10% Two or More Races, and 61% white.

B. Handling Missing Data

Survey responses with >10% of missing cases were discarded so that the analysis only included responses with complete or mostly complete data (>90%). This approach reduced the total sample size but allowed for standard analysis techniques to be conducted [47]. Pairwise deletion was used to handle the remaining missing data. Missing completely at random (MCAR) was assumed during deletion, meaning that missing data are unrelated to all measured variables. This was validated by using Little's MCAR test [48], which was not significant ($\chi^2 = 7854.5$, DF $= 7744$, $p = 0.187$), suggesting that values were in fact missing at random.

C. Exploratory Factor Analysis

The IBM SPSS ® 27 was used for all analyses [49]. An exploratory factor analysis (EFA) was conducted to provide additional validity testing and to address Research Question 1 through the identification of prominent accessibility barrier themes [50]. The scale for the items in the accessibility construct ranged from "0—Strongly disagree" to "3—Strongly agree." Respondents also had the option to respond, "Not applicable or prefer not to respond."

Kaiser–Meyer–Olkin (KMO) and Bartlett's tests were conducted to determine the sample's adequacy. The KMO measure was 0.9, which meets the minimum threshold of 0.6 to determine sample adequacy [51]. Bartlett's test of sphericity was significant ($p \leq 0.001$), indicating sufficient correlation between variables to proceed with the analyses [51]. Three factors reflecting the three UDL guiding principles were extracted using principal axis factoring (PAF). The solution was rotated using an oblique rotation (Promax method) with Kaiser normalization. No cross-loading or high load on any factor occurred following two rounds of extraction and rotation. All remaining variable values satisfied the acceptable range of one item being $\geq$0.32 [52].

TABLE II
BIVARIATE CORRELATION BETWEEN DEPENDENT AND INDEPENDENT VARIABLES

Student Characteristic	Reference Group	Other Group(s)
Gender	Male	Female; TGNC
Race and ethnicity	white	Asian; Black or African American; Hispanic or Latino; Middle Eastern or North African; Native American or Alaskan Native; Native Hawaiian or Pacific Islander; Two or More Races
Engineering major	Aerospace or Mechanical	Biological, Civil, or Environmental; Biomedical; Chemical, Materials, or Textile; Computer or Electrical, Computer Science; Industrial; Other
Year in school	Underclassman (first-year or second-year)	Upperclassman (third-year, fourth-year, fifth-year or higher)
Yearly household income	Lower income bracket ($0-$49,000)	Middle Income Bracket ($50,000-$149,000); Highest Income Bracket (over $150,000)

D. Multiple Linear Regression

To address Research Question 2, we created a multiple regression model, using backwards elimination. We dummy-coded all student characteristics that were string variables to convert into binary variables. Table II shows how student characteristics were dummy coded.

Several tests of linear regression assumptions (e.g., normality, linearity, and homoscedasticity) were run before conducting the regression analysis. Scatter plots and quantile-quantile plots were used to confirm these assumptions were met. We calculated tolerance values to detect multicollinearity in the regression model. All tolerance values were greater than the minimum 0.1 threshold [53]. Next, we conducted bivariate correlation to identify the items and/or constructs correlated with other independent and dependent variables.

Regression analyses were conducted after identifying student characteristics and constructs that were correlated with perceived value of learning. The regression analysis included two steps to predict each of the dependent variables. The first step ran a baseline model with student characteristics (gender, race and ethnicity, year in school, engineering major, and yearly household income) and student perceptions (satisfaction with the instructor's ability to provide accommodations, satisfaction with the institution's ability to provide accommodations, and the degree to which their disability affects their ability to succeed in an online learning environment). The second step ran a baseline model with the four remaining constructs from the EFA analysis (perceived course difficulty in online learning, perceived course difficulty during COVID-19, disability accommodations in online learning, and accessibility). Items were eliminated if their p-value was greater than 0.05 [54]. R squared and F statistic changes were also considered when deciding whether to remove an item from the analysis. The multiple linear regression was rerun following each item removal until the final model was identified.

A post-hoc analysis was conducted to determine the resulting power achieved based on the sample size obtained to conduct these analyses ($n = 450$). A large effect size was calculated using Cohen's f^2 Method ($f = 0.396$), with $\alpha = 0.05$ assumed. The resulting power in the omnibus test was 1.00, meaning there is 100% confidence that the test parameters were enough to detect real significant differences. This high power was influenced by the large sample size which exceeded the 108 participants needed to achieve 99% power.

TABLE III
EFA BARRIERS TO ONLINE LEARNING

Factor	Question	Factor Loading
Action and Expression	The instructor presents information in multiple formats to ensure information is accessible for all their students.	0.517
	The instructor begins each class session with an outline of what will be covered.	0.573
	The instructor summarizes key points throughout the individual class session.	0.778
	The required reading assignments are available online.	0.409
	The key points from the instructional videos for this class are easy to grasp.	0.512
	The instructor uses instructional technologies (e.g., clickers, Rams) to enhance learning.	0.578
	The course learning management systems (e.g., Canvas, Blackboard, or Moodle sites) are clearly organized and easy to use.	0.335
	Students are allowed to demonstrate their comprehension of material in alternate ways.	0.714
	The instructor provides useful feedback on all assignments.	0.686
	The instructor provides timely feedback on all assignments.	0.543
	In this course, I feel interested and motivated to learn.	0.508
	The instructor explains the real-world importance of the topics taught in this course.	0.483
	The instructor supplements lecture and reading assignments with visual aids.	0.588
	The course syllabus clearly describes the learning objectives of this course.	0.772
	The instructor's expectations are consistent with syllabus learning objectives.	0.831
	The instructor provides electronic equivalents (e.g., Word, PDF) of paper handouts.	0.350
Representation	The course syllabus clearly describes the learning objectives of this course.	0.772
	The instructor's expectations are consistent with syllabus learning objectives.	0.831
	The instructor provides electronic equivalents (e.g., Word, PDF) of paper handouts.	0.350
Engagement	The instructor is accessible outside of class time.	0.929
	The instructor is highly approachable to all students.	0.774
	The instructor creates a class climate in which student diversity is respected.	0.632

VI. RESULTS

A. EFA Barriers to Online Learning

The EFA (Table III) revealed that barriers in online learning can be conceptualized into three main categories providing multiple means of: 1) Action and Expression; 2) Representation; and 3) Engagement. These categories reflect the three guiding principles of UDL. Action and

Expression encompassed items referring to the course's delivery. The items that loaded onto this factor describe instructor accessibility, feedback, and comprehension of the material. Representation items referred to how the course's learning objectives are presented. The items that loaded onto this factor describe the clearness of instructor and syllabus expectations for student learning. Engagement included items referring to the classroom environment that the instructor creates. The items that loaded onto this factor describe students' comfort with the classroom climate, approaching the professor for help, and instructor access outside of class.

The summary of items for each factor presented in Table III shows the EFA factors, associated items, and factor loadings. Results from items in Action and Expression suggest that the format of assignments, presentation of material, and feedback from the instructor all contribute to how a student views online course accessibility. There is also a connection between the perceived accessibility and their interest in the course. Participant responses to Representation suggest that a clear explanation of learning objectives and outcomes contributes to how students view the accessibility of their online courses. Finally, the items from Engagement suggest that instructor availability and class climate contribute to students' accessibility.

B. Barriers Most Faced in Online Learning

We conducted a reliability analysis, which provided the mean scores and Cronbach's alpha values for each factor, to find the barriers that students with disabilities face most in the engineering classroom. We examined the average scores for each factor and individual items to identify the accessibility items with the lowest mean scores. The five items with the lowest mean scores ($M < 1.4$) were identified as the barriers most frequently encountered in online learning. These items were as follows.

1) Students are allowed to demonstrate their comprehension of material in multiple ways.
2) The instructor provides useful feedback on all assignments.
3) The instructor provides timely feedback on all assignments.
4) The instructor uses instructional technologies (e.g., clickers, RamCT, etc.) to enhance learning.
5) In this course, I feel interested and motivated to learn.

All items are a part of the Action and Expression factor. This suggests that barriers most faced in online learning stem from how instructors present material and provide feedback to students; all of which relate to students' interest and motivation in the course.

C. Contributions to Perceived Value of Learning through Multiple Linear Regression

We calculated bivariate correlations to investigate the relationships between perceived course values, other constructs, and independent, descriptive characteristic variables. Further validity evidence was calculated using bivariate correlations among independent variables. All bivariate correlation coefficients were less than 0.70, meaning the constructs of each independent variable did not overlap with each other at a problematic level [55].

The significance level of correlation is $\alpha = 0.01$. The correlation results between dependent variables revealed that students' perceived value of learning had a significantly negative correlation with the degree in which disability impacts success in online learning ($r = -0.290$) and perceived course difficulty during COVID-19 and online classes ($r1 = -0.0257$, $r2 = -0.224$). There were positive correlations for perceived value of learning and satisfaction with instructor accommodations ($r = 0.223$), accessibility factors ($r = 0.595$), perception of disability accommodations ($r = 0.350$), and satisfaction with institution accommodations ($r = 0.301$).

There were two multiple linear regression models with similar R squared and p-values. The first model considered course accessibility, online course accommodation ratings, the degree to which their disability affects their ability to succeed in an online learning environment, and their perceived course difficulty during COVID-19, whereas the second model did not consider online course accommodation ratings. The final model was determined by comparing the two models based on how the deletion of the item that differentiated the models changed the R squared and F change values. The deletion of online course accommodation ratings led to a statistically significant decrease in R squared of -0.064, $F(3, 297) = 55.746$, $p < 0.001$. Thus, we used the first model as our final model to evaluate students' perceived value of learning. The final model that considers students with disabilities' course accessibility, online course accommodation ratings, degree to which their disability affects their ability to succeed in an online learning environment, and perceived course difficulty during COVID-19 to evaluate their perceived value of learning in online classes is statistically significant, $R^2 = 0.368$, $F(4, 296) = 43.022$, $p < 0.001$; adjusted $R^2 = 0.359$.

Table IV presents the resulting regression model for predicting students with disabilities' perceived value of learning in online classes. This model explained 36.8% of the variance in perceived value of learning. The set of variables in the model significantly predicted students with disabilities' perceived value of learning in online classes ($F = 43.022$). The model also shows that accessibility factors ($\beta = 0.584$, $p < 0.001$), perceived course difficulty during COVID-19 ($\beta = -0.0187$, $p = 0.006$), perception of disability accommodations ($\beta = 0.094$, $p = 0.064$), and the degree to which disability impacts their success in online learning ($\beta = -0.098$, $p = 0.015$) were significant predictors of students with disabilities perceived value of learning in online courses each on their own.

VII. Discussion

These findings highlight that engineering students with disabilities did experience novel challenges related to the transition to online learning during the initial COVID-19 disruption. Specifically, students reported higher levels of course difficulty in online engineering courses and lower value of their learning in those courses. Generally, engineering

TABLE IV
RESULTS OF MULTIPLE LINEAR REGRESSION MODEL ON INDEPENDENT VARIABLES

Variables	β	Std. Error	Coefficie-nts	t	p
Accessibility Factors *(Construct)*	0.584	0.068	0.464	8.619	<0.001
Perceived Course Difficulty During COVID-19 *(Construct)*	-0.187	0.068	-0.137	-2.759	0.006
Perception of Disability Accommodations *(Construct)*	0.094	0.051	0.097	1.861	0.064
Degree to Which Disability Impacts Success in Online Learning *(Descriptive Characteristic)*	-0.098	0.040	-0.122	-2.44	0.015

students with disabilities reflect similar sentiments about challenges with inaccessibility that are unique to online courses. This finding adds to previous research, which found that a lack of standardized accommodations for online learning exacerbates existing accessibility problems [56].

Research Question 1 focused on analyzing different aspects of accessibility through the UDL framework in order to identify barriers in accessibility. The items converged into a three-factor structure as hypothesized, providing insight into relevant accessibility barriers students with disabilities may face in online classrooms. The identification of these factors and their corresponding items can be used to inform accessibility improvements for instructors in their online classes. The factor, "Provides multiple means of representation" captures multiple ways of describing what will be taught. This provides students with an overview of course material being taught, allowing them to better understand and connect topics. The factor "Provides multiple means of action and expression" captures multiple ways for how students will learn material. This includes presenting content in multiple ways, allowing students to disseminate their knowledge differently, and sustaining student interest throughout the course. The factor "Provides multiple means of engagement" captures multiple ways for students to become interested and retain motivation in their learning. This provides options for recruiting student interest, sustaining effort and persistence, and promoting self-regulation so that students are purposeful and motivated in their learning. The top accessibility barriers most encountered were all a part of the factor, "Provides multiple means of action and expression." This suggests that barriers most faced in online learning stem from how instructors present material and provide feedback to students—all of which relate to students' interest and motivation in the course.

Research Question 2 focused on what affects students with disabilities' perceived value of learning. The final regression model described 36.8% of the variance for students with disabilities perceived value of online learning. The model revealed four variables to be significant predictors: 1) accessibility factors; 2) perceived course difficulty during COVID-19 (negative predictor); 3) perception of disability accommodations; and 4) impact of disability on online learning success (negative predictor). Those with higher levels of agreement for their instructors using UDL accessibility factors and higher average scores for perceived course accessibility were more likely to perceive higher value in their courses. Perceived course difficulty during COVID-19 and impact of their disability in online learning were negative predictors, suggesting that how students perceive their disability's impact on learning and difficulty of courses can significantly affect the value they think that they are receiving from a course.

VIII. LIMITATIONS

We acknowledge that there are several limitations in this study. There are few studies exploring students with disabilities perceptions of online learning prior to [25] and [26] and after the onset of COVID-19 [50], [56]. The lack of prior literature limits our ability to support or compare our findings with others. We have provided details about the demographics of the students who responded to the survey to help the readers judge the transferability of the results to the greater population of students with disabilities in engineering. We conducted this study with primarily Research-Intensive (R1) and Predominantly White Institutions (PWIs), which resulted in the majority (60.95%) of the respondents identifying as white. There was an over-representation of female and TGNC students that is disproportionate to the gender representation of students with disabilities in engineering.

Some students also indicated in the "additional comments" section that it was challenging for them to generalize their courses throughout the survey since they had positive experiences in some courses and negative experiences in others. The wording of the survey may not have allowed students to differentiate between positive and negative experiences since they generalized their experiences to answer the questions. In future deployments of this survey, we are considering wording items so that students can better differentiate negative versus positive experiences to better capture the nuances that can occur in different course offerings.

IX. IMPLICATIONS FOR FUTURE WORK

The ability to engage in classwork virtually is crucial for student success, especially due to the current influx of virtual learning opportunities resulting from the COVID-19 pandemic. The development and use of the OADS survey is part of an ongoing study measuring engineering students with disabilities' experiences in online courses. A better understanding of these experiences will inform future accessibility improvements in virtual engineering courses. The identification of barriers to online learning for students with disabilities resulting from this work will be used to initiate the conversation around accessibility in online learning.

We have identified four main avenues for future research regarding online accessibility for engineering students with disabilities. First, revisiting and further revising the OADS survey to better capture student experiences would provide additional validity evidence to support the use of the instrument. Second, further exploration is needed to better understand the relationships between different items and constructs. Third, expanding the survey's reach and replicating initial findings would further generalizability of the results presented in this study.

The revisions to OADS are based on feedback from participants in the "Additional comments" section and our own reflections. Future work will reword the prompt for the accessibility construct, to focus on participants' most positive and most negative accessibility experiences, opposed to generalizing such experiences. This decision was made after some participants noted in the additional comments section that it was challenging for them to generalize some of their experiences.

Related research will explore how specific accessibility items and factors may relate to other aspects of students with disabilities' experiences in online learning, such as perceived course difficulty. Now that these factors and the most prominent accessibility barriers have been identified, further research needs to be conducted to investigate potential recommendations for improving accessibility in each factor. Future work may also explore relationships between demographic characteristics (e.g., race and ethnicity, SES, gender, and school type) and satisfaction and perception of accommodations.

Future work will also seek to replicate and explain the exploratory findings of UDL's relation to students with disabilities' experiences with accessibility in online learning. Efforts specifically analyzing students' experiences at non-research intensive, Predominately White Institutions (e.g., undergraduate-only colleges, Historically Black Colleges and Universities, and Hispanic-Serving Institutions) will provide broader context to students with disabilities' experiences in online learning. A longitudinal study is also needed to understand the long-term and continued implications of COVID-19 on students with disabilities in higher education, such as persistence, retention, and motivation to pursue college. Given the diverse backgrounds of students with disabilities, additional qualitative research could add greater depth to our understanding of these experiences.

These findings underscore the significance of faculty's role in the online learning experience, specifically for students with disabilities. Future research will examine the presence—or lack thereof—of accessibility training in faculty development. Faculty development trainings must teach instructors not only about accessibility broadly but also provide specifics into how to accessibly present course material, provide feedback, and encourage engagement in their online courses.

X. Conclusion

This study adds new information to the growing body of research for students with disabilities in online learning environments. Our results show that accessibility for engineering online learning can be conceptualized by the UDL principles. Our results suggest that there is a connection between students' experiences with course accessibility and their perceived value of the course. These results support recent calls for broader representation of students with disabilities in STEM. More research is needed to understand barriers to entry in engineering for students with disabilities to better address the overall climate in engineering. This study is an important first step in understanding students with disabilities' experiences in online learning and identifies several nuances to be considered in future work. Designing for disability subsequently increases access for everyone. Thus, a deepened understanding of the current online accessibility barriers will aid in better virtual learning design for all students.

Promoting authentic change for the disabled community cannot be done without critical reflection into the engineering higher education system, which continues to produce a largely white, male, heterosexual, nondisabled body of engineers. An understanding of engineering students with disabilities' experiences in online and in-person settings, around campus, and in the broader higher education community is needed in order to identify, dismantle, and improve the systems and structures that further marginalize students with disabilities. To start, we urge higher education professionals to reflect on the ways in which ableist beliefs, practices, and structures disseminate throughout academia and actively discriminate against students with disabilities.

Appendix

OADS—Accommodations for Virtual Learning (Descriptive Statistics):

Scale: 0: not at all, 1: low impact, 2: medium impact, 3: high impact, and 4: very high impact.

1) To what degree does your disability(s) impact your ability to succeed in an online learning environment?

Scale: Yes/No

2) Do you require specialized technologies (software, hardware, etc.) to work in an online learning environment?
3) Have you requested disability accommodations from your institution?
4) Have you disclosed your disability to your online instructor(s)?
5) Was your request for accommodations granted?

Scale: 0: extremely dissatisfied, 1: dissatisfied more than satisfied, 2: satisfied more than dissatisfied, and 3: extremely satisfied.

6) What is your overall level of satisfaction with your instructor(s)'s ability to accommodate your disability in your online class(es)?
7) What is your overall level of satisfaction with your institution's ability to accommodate your disability in your online classes?

Accessibility Construct Instructions: Think about a particular online course you have or are currently taking. Now, please indicate your level of agreement with the following statements about your typical online engineering courses.

Scale: 0: strongly disagree, 1: disagree more than agree, 2: agree more than disagree, and 3: strongly agree.

1) The instructor presents information in multiple formats to ensure information is accessible for all their students.
2) The course syllabus clearly describes the learning objectives of this course.

3) The instructor's expectations are consistent with syllabus learning objectives.
4) The instructor ties the most important points of the individual class session to the larger objectives of the course.
5) The instructor begins each individual class session with an outline of what will be covered.
6) The instructor summarizes key points throughout the individual class session.
7) The instructor provides electronic equivalents (e.g., Word and PDF) of paper handouts.
8) The required reading assignments are available online.
9) The key points from instructional videos for this class are easy to grasp.
10) The instructor uses instructional technologies (e.g., clickers and Rams) to enhance learning.
11) The course learning management systems (e.g., Canvas, Blackboard, or Moodle sites) are clearly organized and easy to use.
12) Students are allowed to demonstrate their comprehension of material in alternate ways.
13) The instructor provides useful feedback on all assignments.
14) The instructor provides timely feedback on all assignments.
15) In this course, I feel interested and motivated to learn.
16) The instructor provides meaningful assignments.
17) The instructor is accessible outside of class time.
18) The instructor is highly approachable to all students.
19) The instructor creates a class climate in which student diversity is respected.
20) The instructor explains the real-world importance of the topics taught in this course.
21) The instructor supplements lecture and reading assignments with visual aids.

Perceived Course Difficulty (COVID-19) Construct Instructions: Think about your typical engineering class since the beginning of the COVID-19 pandemic. Please answer these questions in regard to how you felt about these engineering courses.

Scale: 0: strongly disagree, 1: disagree more than agree, 2: agree more than disagree, and 3: strongly agree.

Since the beginning of the COVID-19 pandemic…

1) I have experienced greater confusion about the content in my courses.
2) It is more difficult for me to complete the assignments for my courses.
3) I find it more difficult to understand the assignments for my courses.
4) I find it harder to learn new things.
5) I have established strategies to maximize my learning.
6) I have made good grades in school since the beginning of COVID-19.
7) I am comfortable approaching my professor about my need for accommodations.
8) My instructors have been receptive to challenges I face due to my disability(s).
9) My requested accommodations were adequately addressed by my instructors.
10) Professors are familiar with the referral procedures for students with disabilities who need specialized support.
11) In-person classes have been accessible for me.

Perceived Value of Learning Construct Instructions: Please indicate your level of agreement with the following statements regarding the general value you feel that you have gotten out of your online courses.

Scale: 0: strongly disagree, 1: disagree more than agree, 2: agree more than disagree, and 3: strongly agree.

In general, the engineering courses I've taken online have…

1) been stimulating.
2) taught me things that I can apply to other courses.
3) increased my interest in the subject.
4) helped me to learn the subject matter.
5) included valuable materials, such as readings and texts.
6) included assignments that add to my understanding of the subject.
7) taught me things that I consider important to my future.

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