BARRIERS AND FACILITATORS IN TRAINING STUDENTS WITH PHYSICAL DISABILITIES IN SCIENCE AND ENGINEERING LABORATORIES

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Hervens Jeannis, PhD

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There is a dearth of literature in disability and engineering research on the interaction between students with physical disabilities (SwD-P) and their experiences in the postsecondary science and engineering (S&E) laboratory setting. This dissertation extends the information available on this topic. An extensive literature review identifying barriers and facilitators students with physical disabilities encounter in S&E laboratories are described in detail. Psychometric properties of a newly developed nationwide survey were examined and descibed in detail. Empirical evidence on barriers and facilitators in instructional S&E laboratory settings are presented. Survey findings reveal that students experience a wide range of limitations to fully participating in the laboratory, from entering the laboratory to being given passive roles. The survey also reveal a range of supports such as elevators, ramps, accessible course materials, and peers have served as facilitators. The results of this dissertation build on existing literature and can help inform researchers and laboratory instructors on issues surrounding the use of science and engineering laboratories.

TABLE OF CONTENTS

ACKNOWLEDGMENTS XIII

1.0 INTRODUCTION 1

1.1 RATIONALE AND SIGNIFICANCE OF THE PROBLEM 3

1.2 RESEARCH GOALS 4

2.0 FULL-PARTICIPATION OF STUDENTS WITH PHYSICAL DISABILITIES IN SCIENCE AND ENGINEERING LABORATORIES 7

2.1 INTRODUCTION 7

2.2 METHODS 9

2.3 RESULTS 11

2.4 DISCUSSION 17

2.4.1 Barriers 17

2.4.1.1 Learning environment of the laboratory (LE) 18

2.4.1.2 Task execution (TE) 18

2.4.1.3 Built environment (BE) 19

2.4.2 Facilitators 19

2.4.2.1 Learning environment of the laboratory (LE) 19

2.4.2.2 Built environment (BE) 20

2.4.2.3 Task execution (TE) 21

2.4.3 Other Publications and Limitations 22

2.5 CONCLUSION 23

3.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: SURVEY DEVELOPMENT AND PSYCHOMETRICS ... 26

3.1 INTRODUCTION ... 26

3.2 METHODS ... 29

3.2.1 Item Generation ... 30

3.2.1.1 Initial Survey Development ... 30

3.2.2 Item Selection ... 31

3.2.2.1 Translational Validation ... 31

3.2.2.2 Judges ... 32

3.2.2.3 Think-Aloud Procedure ... 32

3.2.2.4 Content Validity Procedure ... 33

3.2.2.5 Content Validity Analysis ... 33

3.2.3 Test-Retest Reliability ... 34

3.2.3.1 Participants ... 35

3.2.3.2 Test-Retest Procedures ... 35

3.2.3.3 Data Analyses ... 35

3.3 RESULTS ... 36

3.3.1 Judges ... 36

3.3.2 Content Validation of Survey Items ... 37

3.3.3 Survey Final Draft ... 43

3.3.4 Reliability ... 45

3.3.4.1 Missing Data Analysis and Demographics ... 45

3.3.4.2 Test-Retest Results: Likert Domain, Likert Item-level, and Dichotomous 50

3.3.4.3 Lowest Reliability 54

3.4 DISCUSSION 56

3.4.1 Content Validity 57

3.4.1.1 BE Content Validity 57

3.4.1.2 TE Content Validity 58

3.4.1.3 LE Content Validity 58

3.4.2 Test-Retest Reliability 59

3.4.3 Limitations 61

3.5 CONCLUSION 62

4.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: INITIAL BARRIER FINDINGS 64

4.1 INTRODUCTION 64

4.2 METHODS 65

4.2.1 Data Analysis 67

4.3 RESULTS 68

4.3.1 Demographics of Sample 68

4.3.2 Barriers 74

4.3.2.1 Barriers - BE 75

4.3.2.2 Barriers -TE 79

4.3.2.3 Barriers - Learning Environment (LE) 84

4.4 DISCUSSION 87

4.4.1 Contributions to S&E Accessibility Literature on Barriers 87
4.4.1.1 Barriers: Built Environment Facility 88
4.4.1.2 Barriers: Task Execution -- Equipment and Tools 88
4.4.1.3 Barriers: Learning in the Laboratory Environment 90
4.4.2 Limitations 92
4.4.2.1 Sample 92
4.5 CONCLUSION 93
5.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: INITIAL FACILITATOR FINDINGS 95
5.1 INTRODUCTION 95
5.2 RESULTS 96
5.2.1 Facilitators 96
5.2.1.1 Facilitators - BE 96
5.2.1.2 Facilitators - TE 101
5.2.1.3 Facilitators - LE 103
5.3 DISCUSSION 104
5.3.1 Contributions to S&E Accessibility Literature on Facilitators 105
5.3.1.1 Facilitators: BE 105
5.3.1.2 Facilitators: TE 107
5.3.1.3 Facilitators: LE 108
5.4 CONCLUSION 109
6.0 CONCLUSION, CONTRIBUTION AND FUTURE RECOMMENDATIONS 110
6.1 RECOMMENDATIONS 110

6.1.1 College science and engineering instructors and laboratory assistants.. 111

6.1.1.1 Built Architectural Environments (BE) 111

6.1.1.2 Task Execution (TE) 111

6.1.1.3 Learning Environment (LE) 112

6.1.2 Policymakers, college science and engineering programs, and university administration 112

6.1.3 Students with disabilities 115

6.1.3.1 TE 115

6.1.3.2 LE 116

6.2 LIMITATIONS 116

6.3 FUTURE WORK 122

6.3.1 Further validity and reliability of the survey 123

6.3.2 Severity of the barriers 124

6.3.3 The complexity of the facilitators 124

6.3.4 Faculty Training Protocol 125

6.3.5 Expansion of work 127

APPENDIX A 128

APPENDIX B 165

APPENDIX C 168

APPENDIX D 175

APPENDIX E 183

BIBLIOGRAPHY 185

LIST OF TABLES

Table 1. Literature Review Results 13

Table 2. Non-Peer-reviewed publications, helpful references that were not included in the results in alphabetical order (N=9) 23

Table 3. Length of Judges Expertise Characteristics 37

Table 4. Items and their I-CVIs used in the survey development 38

Table 5. Survey Item Breakdown 43

Table 6. FPSEA Survey Response Scale 44

Table 7. MCAR Test Results (n=25) include N/A option 45

Table 8. MCAR Test Results (n=25) N/A option as missing data 46

Table 9. Test-Retest Duration Times (n=25) 48

Table 10. Test-Retest Reliability (n=20) Descriptives on Duration 50

Table 11. Item-Level Test-Retest Reliability Results 51

Table 12. Domain Level Test-Retest Reliability Results 53

Table 13. Item-Level Test-Retest Reliability Results in SPSS for dichotomous data 54

Table 14. Seven sub-items that performed the lowest reliability 56

Table 15. Demographic Profile of Survey Respondents (n=228) 70

Table 16. Accessibility of science or engineering laboratories experienced. n (%) 74

Table 17. The most inaccessible laboratory 75

Table 18. Barriers in maneuvering or getting around the laboratory space 77

Table 19. List of AT that to complete laboratory tasks 102

LIST OF FIGURES

Figure 1. Modified flow diagram of the review process according to PRISMA guidelines [31]. [1]Records were excluded if they did not fulfill the inclusion criteria. [2]Records were excluded if they were not peer-reviewed. 11

Figure 2. Stages of the Full Participation in Science and Engineering Accessibility Survey Development 30

Figure 3. CONSORT diagram of participant inclusion 69

Figure 4. Dichotomous Questions on Built Environment (BE) Barriers to Entering the Laboratory 76

Figure 5. The following features were reported as barriers to entering the laboratory 77

Figure 6. Majority of participation limited to the following activities. 80

Figure 7. Percentages Related to Laboratory Setup, Accessing Course Materials, and Operating Laboratory Equipment 81

Figure 8. Dichotomous Questions on Operating Laboratory Equipment and Tools 83

Figure 9. The following were agreed statements in handling laboratory tools and equipment 83

Figure 10. The following were reported to be true statements about the laboratory equipment 84

Figure 11. Statements regarding instructors or lab assistants while working the laboratory space 85

Figure 12. Additional Perceptions of Laboratory Assistants and Instructors 86

Figure 13. Percentages of SwD-P receiving assistance from Peers and Available Programs to Prepare Instructors 86

Figure 14. The following were reported as easy when entering the laboratory space 97

Figure 15. The following made it easy to use the laboratory space 99

Figure 16. The following were reported as helpful laboratory features 100

Figure 17 The following safety procedures were addressed in the laboratory environment 100

Figure 18. The following were reported to be helpful to operating the laboratory equipment... 103

Figure 19. Helped in fully participating in the laboratory 104

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- *Philippians 4:13*

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1.0 INTRODUCTION

Careers in the science, technology, engineering and mathematics (STEM) fields are at risk of recurring vacancies due to the lack of trained professionals. By 2018, 92% of STEM jobs are projected to require post-secondary education or training [1]. Correspondingly, there is an overall shortage of educated or trained individuals to produce qualified candidates in STEM-oriented fields[2]. One way our nation can help overcome this concern is through diversity initiatives that develop the skills of people with disabilities (PwD) in STEM [3].

Approximately 22% of the United States adult population has some form of disability [4]. The highest level of impairment of the adult population in the U.S. are those with physical impairments (e.g. difficulty walking) at 13%, followed by other types of impairments in the U.S. which include cognitive impairments (e.g. difficulty concentrating) at 10.6% and vision impairments (e.g. difficulty seeing) at 4.6% [4]. Similarly reported in the Census, physical impairments (12.6 %) are one of the most prevalent disabilities reported [5]. Brault [5] and the Social Security Administration defines physical impairment as those with upper and lower body limitations (e.g. difficulty walking, climbing stairs, grasping, lifting, pushing, pulling, sitting, standing, crouching, and reaching) [5], [6]. Although physical impairment constitutes a large portion of adults with disabilities, students with physical disabilities remain a small portion of the undergraduate population [7].

Higher education attainment remains a challenge for students with disabilities (SwD) pursuing Science and Engineering (S&E) fields. Over 2.2M undergraduate students with a disability make up 11% of the college student population [8]. While the majority of the students have cognitive impairments (8.1%), a smaller percentage (2.1%) report having a physical impairment (e.g. difficulty walking) [7]. The rate of enrollment in S&E programs in post-secondary institutions is 23% (0.59M), comparable to the rate of students who enroll without a disability (25%) [8]. Despite these similarities, in 2015, one-third of the adult population over 25 (33%) held a bachelor's degree, while only 17% of the adult population with a disability held a bachelor's degree [9]. Although the National Science Foundation (NSF) reports on the percentage of underrepresented groups that earn bachelor and master's degrees in S&E, no data exists for bachelor and master's degree recipients with disabilities. Still, NSF emphasizes that PwD remain underrepresented and underemployed in STEM careers [8], [10], [11]. PwD with at least a bachelor's degree constitute 8.4% of the workforce and 7.2% of the science and engineering workforce [12].

Congress is also in support of education attainment and career advancement of students with disabilities. In 2014, section 503 of the Rehabilitation Act of 1973 was amended to require that employers be more intentional in hiring and retaining individuals with disabilities [13]. Regulations based on the Rehabilitation Act of 1973 and the Americans with Disabilities Act (ADA) of 1990 focus not only on employment but also on post-secondary education. These regulations require colleges and universities to become accessible for PwD by providing reasonable accommodations that help make STEM degrees and careers attainable for students with disabilities (SwD) and students with physical disabilities SwD-P at large [10], [14].

1.1 RATIONALE AND SIGNIFICANCE OF THE PROBLEM

Any person can become disabled at any point in life. Individuals with disabilities constitute a unique minority group irrespective of age, gender, race, and religion. Yet, society is far from being well-prepared to embrace people with disabilities, particularly people with physical disabilities. Difficulties for people with disabilities are not limited to entering doors and using restrooms [15], other challenges include obtaining degrees in science and engineering fields [14], [16]. Molding S&E employees with disabilities mainly occurs during postsecondary education [14]. Properly training students with disabilities (SwD) in S&E requires an understanding of the issues and intervention from many constituents in the educational pipeline [17]. For example, Norman, Caseau, and Stefanich's study [18] focused on the perceptions of science teacher training, teaching experiences, needs, and attitudes regarding teaching students with disabilities. Their study of science teachers and professors who teach science methods found that despite science educator's willingness to acquire more training, these educators are at a disadvantage when it comes to teaching SwD. First, instructors lack experience and training to teach SwD. Second, instructors are not cognizant of the best practices for teaching SwD and hold stereotypical views of the capabilities of SwD [18]. Third, without fully understanding or assessing the capabilities of what SwD can or cannot do, some S&E laboratories instructors relegate SwD to simply observe [19] or task SwD with passive activities (e.g. taking notes, writing papers, programming software) [14] rather than be given more active roles to participate in hands-on science investigations [11], [20], [21]. The results from this study suggest need for further research on this topic.

While the Norman and colleagues [18] perception study investigated the issue of teaching science to SwD from the instructors' perspective, society has yet to fully understand the implications beyond high-school for SwD who want to pursue a career in S&E. Moreover, researchers have yet to explore the same topic from the students' perspective. Simply put, from an SwD's perspective, what are the barriers and facilitators of SwD-P in post-secondary S&E laboratory courses? To understand this issue further, this exploratory study seeks to help identify the barriers and facilitators for SwD-P in the instructional laboratory space. A closer look at the S&E career pipeline in higher education from the perspectives of direct stakeholders (e.g. SwD-P) is a critical step to uncover potential issues in S&E laboratories. Given the dearth of literature in disability or engineering research on SwD-P and their experiences in S&E laboratories, the main purpose of this work is to help identify barriers and existing accommodations that organizations and instructors can use to enhance SwD-P access to S&E fields. Beyond the instructors' perspectives, this survey-based research adds to the literature on SwD by providing an understanding of the students' perceptions of their experiences with hands-on investigations in S&E laboratories. Additionally, the preliminary development of a survey can help to generate empirical evidence pertaining to barriers and facilitators SwD-P encounter in S&E laboratories to help inform researchers and instructors about innovative ways to improve the learning experience of people with physical disabilities.

1.2 RESEARCH GOALS

The goal of this work was to investigate, identify, and document barriers and existing accommodations to examine strategies that organizations and instructors can take to accommodate students with physical disabilities thus helping these students to obtain hands-on training in instructional S&E laboratories. At the completion of this study, the expectation was that a list of barriers and facilitators would be available to help direct future research and to better equip instructors and institutions in helping students with physical disabilities fully participate in science and engineering laboratories. Below are the research study questions and aims:

Research Question I

What are the barriers (e.g. architectural, equipment, tooling, educational) to full participation in instructional S&E laboratories for students with physical disabilities?

Aim I

Investigate, identify and document perceived facility, equipment, tooling and learning barriers that students with physical disabilities may encounter in an instructional S&E laboratory

Research Question II

What are the existing strategies or modifications (e.g. adaptations and redesign), for full participation instructional S&E laboratories can use to assist students with physical disabilities?

Aim 2

Investigate, identify and document facilitators (e.g. physical accommodations, workspace modifications, equipment redesign, tools, strategies, and programs) that has been made for students with physical disabilities in an instructional S&E laboratory

To identify barriers to hands-on participation for individuals with physical disabilities, a systematic review of SwD was conducted with emphasis on students with physical disabilities (SwD-P). The results of this systematic review is presented in chapter 2. This research identified previously published (primarily STEM-focused) literature on the barriers and facilitators associated with students with disabilities in academic institutions (i.e. universities and colleges). Chapter 3 conveys the development and psychometric properties of nationwide survey. Next, Chapters 4 and 5 describes the initial findings of the survey. The dissertation concludes with Chapter 6. This final chapter provides a discussion of the implications of the results and future recommendations.

2.0 FULL-PARTICIPATION OF STUDENTS WITH PHYSICAL DISABILITIES IN SCIENCE AND ENGINEERING LABORATORIES[1]

2.1 INTRODUCTION

Science, technology, engineering and mathematics (STEM) fields are at risk of being unfilled due to lack of trained professionals. By 2018, 92% of STEM jobs are expected to require post-secondary education or training [1]. Correspondingly, there is an overall shortage of educated or trained individuals to produce qualified candidates in STEM-oriented fields [22]. People with disabilities (PwD) may be considered to help overcome these shortages. PwD remain underrepresented and underemployed in STEM careers, despite adequate training [10]–[12]. PwD with at least a bachelor's degree constitute 8.4% of the workforce and 7.2% of the science and engineering workforce [23].

Few research studies address students with physical disabilities (SwD-P) that may have different barriers not accounted for and not enough empirical evidence exists in examining barriers and facilitators for SwD-P [20], [24]–[26]. Ten million working-age adults (roughly 5% of the United States population) have a physical disability—the most prevalent of impairment in the working-age group [27]. Physical disability in this discussion is defined as an orthopedic and neurologic impairment that require the use of an assistive device, such as a cane, walker, scooter, prosthetic limb, or wheelchair.

[1] H. Jeannis, J. Joseph, M. Goldberg, K. Seelman, M. Schmeler, and R. Cooper, "Full-participation of Students with Physical Disabilities in Science and Engineering Laboratories," Disabil. Rehabil. Assist. Technol., pp. 1–8, 2017

In 2014, section 503 of the Rehabilitation Act of 1973 was amended to require employers to be intentional in hiring and retaining individuals with disabilities [13]. Regulations based on the Rehabilitation Act of 1973 and the Americans with Disabilities Act (ADA) of 1990 focus not only on employment but also on post-secondary education. These regulations require colleges and universities to be accessible and to provide reasonable accommodations to help make STEM degrees and careers attainable for students with disabilities (SwD) at large, which includes SwD-P [10], [14]. There seems to be a hindrance to the advancement through the science and engineering (S&E) pipeline for SwD. For SwD, the rate of enrollment in science and engineering programs in post-secondary institutions is 23%; however, a lower rate (7%) of SwD holds a bachelor's degree and works in the STEM fields [12]. The incongruity between enrollment and graduation rates suggests that there may be barriers at the post-secondary education level which may hinder SwD from succeeding in STEM programs.

To properly train SwD in STEM, active participation of institutions, educators, and corporations is necessary [17]. Addressing barriers may help to address future expected shortages in the talent needed for STEM employment and increase diversity in science and engineering-related fields. One area of concern notes that SwD are relegated to observe [19] rather than actively participate in S&E laboratory activities [11], [20], [21]. Moreover, SwD are often tasked with taking notes, writing papers, programming software, and other passive activities [14]. A full participatory approach may encourage SwD to become more active with STEM related career opportunities [11], [28].

A commonly used framework in scientific research (e.g. survey research) on disability is the International Classification of Functioning, Disability and Health (ICF) [29], [30]. According to the ICF, the environment in which people live and conduct their lives is either a barrier or facilitator to the person's activity and participation in their environment [29]. The ICF's taxonomy of activities, which describes the task and execution of an individual, serves as a critical component to help classify the barriers and facilitators of S&E laboratories. The Accreditation Board for Engineering Technology (ABET), a governing body over standards for engineering and science education, supports the ICF in classifying barriers and facilitators found in the literature.

In order to better understand why hands-on participation continues to be less accessible to individuals with certain disabilities, an extensive review on SwD was conducted with emphasis on SwD-P. This research identified previously published, primarily STEM-focused literature on the barriers and facilitators associated with students with disabilities in academic institutions (i.e. universities and colleges). Within the discussion section are two major sections: barriers and facilitators. This review will provide a compiled list of challenges and strategies that can be employed in order for SwD to participate fully and successfully in STEM laboratories.

2.2 METHODS

A comprehensive review was conducted for literature between 1991 and 2015 in scientific and medical electronic databases including Cumulative Index to Nursing & Allied Health Literature (CINAHL) (1982-2015), PubMed (1951-2015), SCOPUS (1966-2015), Web of Science via Web of Knowledge (1945-2015), IEEEXplore (1982-2015), Engineering Village (INSPEC, COMPENDEX) (1969-2015), ERIC (1974-2015), Business Source Complete (1919-2015), using combination of keyword search terms, corresponding Medical Subject Headings (MeSH) terms and synonyms for *accommodations, advanced manufacturing, additive manufacturing, assistive technology, barriers, engineering, facilitators, instructor, laboratory, persons with disabilities,* *science*, *STEM education*, *students with disabilities,* and *technology*. The inclusion criteria include (1) peer reviewed literature reviews, empirical studies, descriptive studies, and design and development articles from both empirical and non-empirical studies pertaining to students with disabilities or employed individuals with disabilities, (2) published in the English language, (3) published after January 1, 1991 (after the Americans with Disabilities Act was established) and before December 31, 2015, and (4) focused on barriers for SwD, accommodations for SwD or SwD within science and engineering, or science and engineering within the workforce. We excluded papers that referenced barriers and facilitators for SwD but focused on unrelated topics such as recreational activities and fitness, or did not focus on facilitators or barriers to help to promote participation. An initial search was based on the table of contents and bibliographic references from the 2014 American Association for the Advancement of Science (AAAS) Journal, *College to Careers: Fostering Inclusion of Persons with Disabilities in STEM* [14]. Based on authors listed in the initial AAAS publication and name repetition, we were able to conduct more in-depth searches based on authors' names to obtain more publications on the same topic from key authors. There was also a manual screening of reference lists of pertinent studies for any missed articles. Additional articles were searched using the SciTrain publication database last updated in 2010, developed by the Georgia STEM Accessibility Alliance. The SciTrain search filters included any publications that were related to physical disabilities, science and technology (since engineering was not listed), and science and technology related courses, irrespective of the listed skills and age groups. Results from the overall search process are outlined in Figure 1.

Two hundred thirty-three articles met the initial review criteria. Two authors (HJ and JJ) with disability research experience reviewed titles and abstracts with these keywords to validate their inclusion in the review. Full-text articles were reviewed if the titles and abstracts seemed promising to meet the full inclusion criteria, and the authors decided to exclude or include the article following review. All publications that provided a description of a barrier and/or facilitator or both for students with disabilities or employed individuals with disabilities were reviewed.

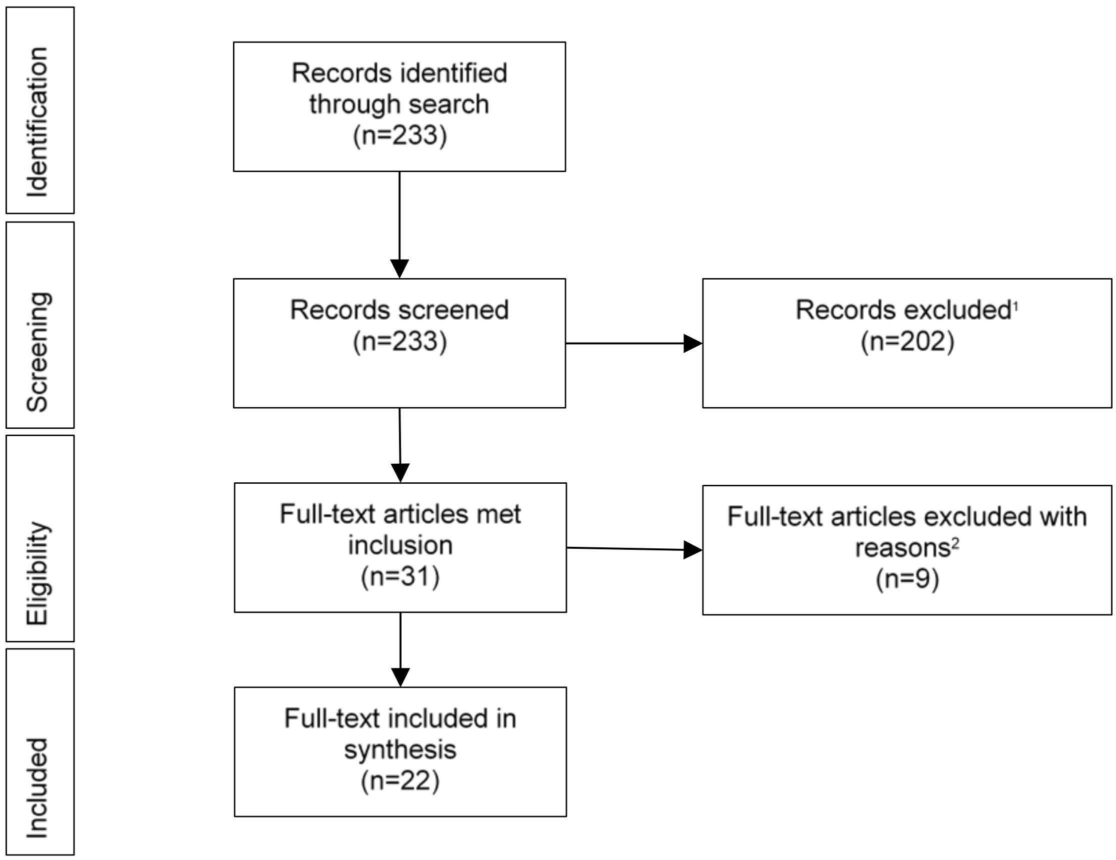

Figure 1. Modified flow diagram of the review process according to PRISMA guidelines [31]**.** [1]**Records were excluded if they did not fulfill the inclusion criteria.** [2]**Records were excluded if they were not peer-reviewed.**

2.3 RESULTS

After careful review, the two authors came to the consensus that twenty-two peer-reviewed articles address issues related to the barriers or facilitators of students with physical disabilities in a laboratory setting. Table 1 highlights specific details regarding all the 22 articles that met the inclusion criteria. From the 22 articles, similar articles were combined in the table, based on continuation from a previous study or mention of the same unique technology or program. In general, not all the articles examined the barriers or facilitators in science or engineering laboratories for SwD explicitly; however, all articles mentioned some form of barrier or facilitator as part of the overall article. Seventeen articles mentioned barriers, and six articles mentioned possible barriers for SwD came directly from the study. Of these six articles, only McDaniel et al. [25] and Phillips and Giasolli [26] mentioned barriers specifically for SwD-P. Most of the articles (21) mentioned a facilitator to help SwD-P in a science and engineering laboratory setting. Fourteen articles mentioned facilitators as an output of the study, compared to 18 that was not an output from the study (e.g. listing recommendations or strategies). Four articles were based on the design, development, and evaluation of a product or program to enhance the instructional laboratory environment. Only five articles specifically mentioned SwD-P [16], [24], [26], [32], [33].

The barriers and facilitators identified in the literature were grouped into three categories using domains of Activities of Participation within the ICF. The categories used were 1) learning (L) environment of the physical science and engineering laboratory, including interaction with others (e.g. student peers, and laboratory instructors); 2) the physical built environment (BE) of the laboratory; 3) and the tasks needed to execute (TE) in the laboratory space (e.g. setting up or using laboratory equipment or tools). Information found within the literature is discussed in the next section.

Table 1. Literature Review Results

Article	Resource type	Sample	Barriers related to instructional laboratories	Primary facilitator discussed
[34][1]	Empirical study – Surveys, Interviews	20 Instructors/Staff who taught SwD (6-12 grade science, university and staff)	Difficulty accessing lab equipment to perform lab tasks (TE)[1]; Instructors feel ill-prepared in teaching SwD-P (L)[2]; Insufficient collaboration between DRS staff & instructors (L)[2]	Professional development program for instructors – CLASS (L)[1-2]
[35][2]	Non-empirical study - report	44 instructors; 22 secondary school SwDs (sensory, physical, and cognitive disabilities)		
[28][3]	Non-empirical study - Report – descriptives	None	None	All-in-one auditory science lab tool (TE)[3-4]
[11][4]	Empirical study- Survey and chemistry class session	91 students with visual impairments (e.g. blind, low vision)		
[36][5]	Non-empirical - descriptives	None	Lack of awareness of AT to access lab equipment (L)[6]; Difficulty accessing documents in alternative formats (TE)[5];	Professional development program for instructors and accessible training program for SwD -- DO-IT (L) [5-6]
[20][6]	Empirical study – Surveys	73 students with disabilities (mobility(42%), sensory, learning disabilities);		
[16][7]	Empirical study - design, development and evaluation of microscope	Eight students with various upper motor and lower limb impairments	Mount specimen to slides (TE)[7], load slides to microscope (TE)[7]; focusing microscope (TE)[7]; SwD can only peer through lens (TE)[7]; SwD-P severe not able to operate a traditional microscope (TE)[7-8]	AccessScope -- an alternative microscope workstation(TE) [7-8]
[21][8]		Ten college students with upper mobility or visual impairments		

Table 1 (Continued)

Article	Resource type	Sample	Barriers related to instructional laboratories	Primary facilitator discussed
[24][9] [37][10]	Empirical study – case study & design Non-empirical study-design and Development of simulation	One neuroscientist with quadriplegia evaluated environment	Inaccessible labs (BE)[9]; visually obstructive lab environments (BE)[10]; overcrowded equipment (TE)[10]; high workbenches (BE)[10]	3D simulated biomedical lab environment (ABIL) (BE)[9-10]; laboratory work triangle (e.g. fume hood, sink & workbench) (BE); Modified lab sinks, lowered countertops, remove cabinets for leg clearance, shallow sinks, faucets moved closer to user, accessible emergency exits showers, & eyewash basin, two different lengths of shower pulls (BE)
[38]	Empirical case study - Interviews	One high school math instructor; one high school student with a learning disability	Low expectations of instructors (L); lack of adequate accommodations (TE)	Provides recommendations e.g. instructional content should be accessible (TE); Mentoring SwD (L)
[32]	Empirical study - 4 semesters of surveys	222 college students from a STEM laboratory course (both able-bodied and SwDs); students with disabilities unspecified	Time to complete tasks (TE)	Video-recording, digital camera, (TE)
[39]	Empirical study – archived data pre-post survey	46 students total, 20% SwD, unspecified by type	None applicable	REU programs (L)
[26]	Empirical study - Case studies	SwD-cognitive, physical, sensory;	Difficulty grasping & manipulating tools (TE); Unavailable AT (TE) Lowest shelf 5” from the ground (BE)	Using jigs or fixtures instead of hands (TE); remote controlled vice or simple foot operated clamp (TE), reacher-system (TE)
[40]	Empirical- working conference with panel presentations	66 profs from local community college, state dept. for blind, middle-high school teachers, college, DRS, admins, and parents	Lab assistants who do too much to help students in lab (L); student’s failure to disclose need for accommodation (n/a); lab equipment is inaccessible (TE);	Assistive technology (unspecified), talking calculators, smart boards (TE); lab assistants who assist in making the work accessible but, do not complete the work for students (L)

Table 1 (Continued)

Article	Resource type	Sample	Barriers related to instructional laboratories	Primary facilitator discussed
[41]	Non-empirical study - literature review - Searched textbooks, special education and science education journals	SwDs in K-12, (cognitive, emotional and behavioral, physical, visual and hearing impairments) did not distinguish disabilities well	Writing/recording data (TE); instructors feel lack of awareness/training to support inclusive instruction (L)	Manipulated laboratory equipment (TE)
[33]	Non-empirical – development and design paper with an example experiment setup	SwD-various (physical, cognitive)	None applicable	Lists strategies for creating an accessible S&E laboratory e.g. labs need to account for: physical access to labs (BE); physical access to facilities within labs (BE); access to AT within labs (TE); access to personal support personnel (L); remote access of lab(TE);
[42]	Non-empirical-descriptive	SwD-various (specified within text)	None applicable	Provides recommendations e.g. height adjustable tables (BE); interface lab equipment with/ computer & speech output (TE); lab partner/scribe to help participation (L); comp. controlled lab equipment w/ alt. input devices (e.g. alt. keyboard, speech) (TE); modified science equipment (SwD-P);
[43]	Non-empirical - Descriptives/discussion paper	High school SwD – (unspecified)	Low expectations from others (L)	Lists recommendations for accessible spaces e.g. collaboration between special education staff & instructors (L); SwD have designated lab partners (L); informed on types of accommodations needed at the beginning of school year (L); have lab space workstation clearance for wc users (BE);
[44]	Non-empirical – descriptive on success of program	SwD (no distinctions)	Inaccessible lab equipment (TE)	ACCESS multi-component training program for SwD (L);

Table 1 (Continued)

Article	Resource type	Sample	Barriers related to instructional laboratories	Primary facilitator discussed
[25]	Descriptive with embedded case study in chemistry, experiment, tested by 1 wheelchair user and chemistry class;	SwD-P (student with Cerebral Palsy)	Dealing with hazards (e.g. broken glass) (TE)	None applicable
[45]	Non-empirical study - Report - descriptives - summary of 4-yrs of NSF research	SwD-various (unspecified)	None applicable	Lists strategies for instructors e.g. instructors collaborate with SwD; instructors find out about available campus student support (L); have students pair for hands-on activities (L); use multi-sensory approach in instruction (L); use technology to overcome barriers (L);

2.4 DISCUSSION

2.4.1 Barriers

Little evidence was found for specific barriers and facilitators in S&E laboratories for SwD-P. Much of the literature that examined barriers was anecdotal and not based on empirical research. Moreover, three of these articles did not specifically examine SwD-P [32], [38], [40]. One case study on a student with a cognitive disability pointed to inadequate accommodations and negative attitudes of instructors [38]. French et al. [32], which concentrated on cognitive disabilities, evaluated surveys over the course of four semesters, and identified inadequate time for students to complete the laboratory tasks as the most significant barrier. Rule et al. [40] received input from instructors and administrators on barriers, but did not distinguish barriers for students with physical impairments. Phillips and Giasolli [26], and McDaniel [25], were the only studies to distinguish barriers for SwD-P. The sole barrier found in McDaniel's [25] article focusing on safety mentions dealing with broken glass as a hazard [25], which can occur during task setup or equipment use or anywhere within the process of executing a laboratory task. Phillips et al. [26], presented several short case study scenarios on SwD-P from various disciplines in post-secondary environments. Phillips et al. [26], provided non-specific barriers (e.g. assistive technology not available) and more helpful information (e.g. difficulty grasping and manipulating tools; the lowest shelf able to be reached is 5 inches from the ground). Other studies are discussed below.

2.4.1.1 Learning environment of the laboratory (LE)

While the majority of researchers focused on task execution-related barriers, fewer researchers (5 articles) focused on barriers pertaining to the laboratory's learning environment, which include the interaction between SwD-P and others (e.g. instructors and peers). The literature emphasizes that SwD-P often are relegated to observer status or given other work to do in lieu of active engagement in the laboratory [14], [19]. However, this information is primarily anecdotal and fails to meet scientific rigor. According to the literature, SwD-P are often overlooked or discouraged from pursuing STEM [11], [20], [21]. Most issues presented in the literature surrounding the learning environment relate to the instructors and those who interact with SwD-P [35], [40], [41], [43], [46]. Studies find that instructors feel they have a lack of training or feel ill-prepared to teach SwD-P [35], [41]. Other barriers related to instructors and students included an insufficient collaboration between disability services staff and instructors [35] and unaccommodating instructors [46]. However, one report mentioned that lab assistants are too accommodating and do too much to assist SwD-P in a lab [40]. One article reported a barrier is the lack of awareness of assistive technology (AT). One barrier from a case study on learning barriers mentioned that peer and instructors may have low expectations of SwD-P [43].

2.4.1.2 Task execution (TE)

Twelve articles were related to task execution. Four articles remarked that laboratory equipment was inaccessible, without providing any detail [19], [40], [44] or lack of adequate accommodations [38]. The remaining articles shared more specific information that could apply to SwD-P, such as not being able to operate a traditional microscope [16], [21]; difficulty grasping and manipulating tools [26]; difficulty accessing documents in alternative formats [36]; overcrowded equipment [37]; difficulty writing and recording data [41]; and dealing with hazards (e.g. broken glass) [25].

2.4.1.3 Built environment (BE)

Two of the studies focused on barriers related to the built environment [24], [37]. Research mentions that laboratories are inaccessible [24]. One study pointed out that laboratories are visually obstructive and have high workbenches [24]. Another study identified the lack of accommodations for someone with bending issues (e.g. the lowest shelf was only 5 inches above the ground) [26]. Another barrier referred to a SwD-P who opted out of disclosing their disability which prevented the student from receiving accommodations [40].

2.4.2 Facilitators

2.4.2.1 Learning environment of the laboratory (LE)

Most of the extant literature (12 articles) focused on instruction-related facilitators for SwD-P in a physical laboratory environment. Four articles mentioned non-physical tools that can indirectly help SwD-P in learning in the laboratory, such as summer research internships [39]; mentoring [38]; instructors helping students learn about available student support on campus [45]; or access to personal support personnel [33].

The literature provided insight on relationships and interaction with others in the laboratory space [40], [42], [43], [45]. Three of the articles provided recommendations that SwD-P should be paired with lab partners to help participation that require hands-on activities [36], [43], [45]. Other articles recommended that instructors collaborate with SwD-P [45] or with special education staff [43]. However, the latter article concentrated on instructors in the K-12 setting. One article that provided input directly from instructors on lab assistants who assisted in making the work accessible conveyed that lab assistants should not complete the work for students [40].

Two articles made recommendations for instructors to help students learn in the laboratory environment [43], [45]. One article listed general strategies for instructors such as having a multi-sensory approach in instruction for SwD-P [45] and allow SwD-P to use AT to overcome barriers [45]. A more recent article suggested that instructors should be knowledgeable about types of accommodations at the start of the school year [43].

Very few professional and development programs for instructors have been developed such as Disabilities, Opportunities, Internetworking and Technology (DO-IT) [20], [36] and Center's Lesson Adaptations for Student Success (CLASS) [19], [35]. The DO-IT program has been growing over the past twenty years and has successfully taught instructors to be more confident in teaching SwD-P [20], [36]. As a result of the CLASS program, instructors feel more equipped for helping SwD-P reach equitable learning opportunities in STEM fields [19]. Accessible training programs for SwD-P have been slowly developing as well such as Accessing Career Choices in Engineering and Sciences (ACCESS) [44] and DO-IT, a program that applies to both students and instructors [20], [36]. One of the four parts of the ACCESS program gives able-bodied students an opportunity to partner with SwD-P to find barriers in a laboratory space [44].

2.4.2.2 Built environment (BE)

Five articles focused on the physical built environment or provided recommendations and strategies for science and engineering laboratories [24], [33], [42], [43]. One article pointed out the importance of physical access to laboratories and facilities within the laboratory [33]. One method for making an engineering laboratory accessible is redesigning the facility entirely [24]. Blueprints were developed at Purdue University to make the laboratory facility more accessible [37]. From this same laboratory, a 3D simulated biomedical lab environment (ABIL) was developed to enable SwD-P to actively participate in laboratory activities. Duerstock et al. [24]

also used a work triangle consisting of a fume hood, sink and work bench for easy access to frequently used machines in a biomedical laboratory. Other modifications used in this simulated environment included modified lab sinks, lowered countertops, removed cabinets for leg clearance, shallow sinks, and faucets moved closer to the user [24]. It is useful to find out from people with physical disabilities if a simulated environment would allow them to fully participate in the laboratory activity. Two other recommendations to adapt the physical laboratory space were to have adjustable table heights [42]and have lab space workstation clearance for wheelchair users [43].

Hilliard et al. [37] discussed the importance of safety for accommodations [37]. Easily accessible emergency exits and showers have been mentioned in the literature as facilitators [37]. Hilliard et al. [37] also references an emergency eyewash basin moved further away from the supply line for easier access. Other modifications included: 1) two different lengths of shower pulls, so wheelchair users and able-bodied users can use the machines; 2) raising eyewash basins for knee clearance; and 3) moving wash jets closer to end users to remove the risk of leaning forward too much and falling [37].

2.4.2.3 Task execution (TE)

Few researchers have developed and evaluated technologies that would help SwD-P participate in S&E laboratories [11], [16], [21], [28]. An older article related the development of a reacher-system for SwD-P [26]. More recent articles discussed developing newer products such as AccesScope, an alternative microscope station used by SwD-P [16], [21] and an all-in-one auditory science laboratory tool for students with visual impairments [11], [28]. Other researchers suggested off-the-shelf products to help execute tasks and learn such as using video-cameras or digital cameras [32], smart boards [40], and talking calculators [40].

Several researchers (4 articles) showed assistive technology can be critical in creating an accessible laboratory [33], [40]–[42]. Although one article that obtained information from instructors deemed AT as important, the study did not specify any type of AT [40]. Two of the older articles recommended manipulating or modifying laboratory equipment [41], [42]. Some of the recommendations provided included interfacing laboratory equipment with a computer that provides speech output, or having alternative input devices such as alternative keyboards [42]. Newer research emphasizes that using an alternative approach to accessing laboratory equipment or accessing AT within laboratories are strategies for creating an accessible S&E laboratory [33]. One article described how accessing laboratory equipment remotely can serve as a facilitator [33].

2.4.3 Other Publications and Limitations

Additionally, publications such as information from websites, books, manuals and guides written by sole authors were found that may be helpful, but were not added to this review because they were not considered peer-reviewed. These can be found in Table 2. Research-based surveys or interviews may be an appropriate next step to quickly collect critical information from stakeholders (e.g. SwD-P and S&E instructors) directly on participation [47]. This review was limited to two reviewers. A future review may include more reviewers and a scoring sheet to evaluate all the articles. This review also was limited to peer-reviewed articles; a future review may wish to extend the review to non-peer-reviewed articles. There was a lack of empirical studies on the impact of these barriers found related to participation in the S&E laboratory. There may have been other search terms used to find other articles.

Table 2. Non-Peer-reviewed publications, helpful references that were not included in the results in alphabetical order (N=9)

Bernhard, K. and J. Bernhard (1998). SCIENCE FOR ALL–using microcomputer based laboratory tools for students with physical disabilities. International Conference Practical Work in Science Education. Copenhagen.
Burgstahler, S., Duclos, R., & Turcotte, M. (2000). Preliminary Findings: Faculty, Teaching Assistant, and Student Perceptions Regarding Accommodating Students with Disabilities in Postsecondary Environments. Seattle: University of Washington, DO-IT. (ERIC Document Reproduction Service No. ED456718)
Burgstahler, S., & Nourse, S. (2000). Accommodating Students with Disabilities in Math and Science Classes: A Resource for Teachers [and Videotape].
Heidari, F. (1996). Laboratory Barriers in Science, Engineering, and Mathematics for Students with Disabilities.
Humphrey, J. (1992). Physically Challenged Students in the Microcomputer Lab: Burden or Opportunity?. Collegiate Microcomputer, 10(2), 68-70
Moon, N. W., Todd, R. L., Morton, D. L., & Ivey, E. (2012). Accommodating students with disabilities in science, technology, engineering, and mathematics (STEM): Findings from Research and Practice for Middle Grades through University Education. Atlanta, GA: Center for …. Atlanta. Retrieved from http://advance.cc.lehigh.edu/sites/advance.cc.lehigh.edu/files/accommodating.pdf BOOK
NSTA National Science Teachers Association 1840 Wilson Boulevard, Arlington VA 22201. Science for Students with Disabilities | Motor Impaired / Orthopedic Disability. (http://www.nsta.org/disabilities/motor.aspx) (Copyight 2015)
Rule, A. C., Stefanich, G. P., Haselhuhn, C. W., & Peiffer, B. (2009). A Working Conference on Students with Disabilities in STEM Coursework and Careers. Online Submission
Sukhai, M. A., Mohler, C. E., Doyle, T., Carson, E., Nieder, C., Levy-Pinto, D., ... & Smith, F. (2014). Creating an Accessible Science Laboratory Environment for Students with Disabilities.

2.5 CONCLUSION

This review of the literature addressed the barriers and facilitators encountered by people with disabilities to help identify challenges and solutions for SwD-P in STEM laboratories. Most of the literature found did not focus on physical disabilities. The paucity of research on barriers and facilitators to participation in instructional S&E laboratory environment for students with disabilities is clear. Although 233 publications were found in the initial search, only 22 peer reviewed publications met the search criteria. None of the studies directly found barriers or facilitators to SwD-P in science or engineering laboratories within postsecondary environments. There was a lack of empirical evidence that focused on SwD-P in post-secondary level education and STEM laboratories combined. It is unclear whether this is because the SwD-P population has been neglected, or whether there are few barriers to report. Many of these articles generalize the term “disabilities” and did not clearly differentiate between the type of disability (e.g. sensory and physical). This unclear distinction makes it difficult to clearly determine what barriers are associated with SwD-P. Future research should distinguish barriers for specific types of disabilities. Narrowing the scope to physical disabilities will help to solidify a more accurate set of barriers and facilitators for a specific population. Uncovering information related to SwD-P may help to advance the instructional culture, institutional practices, and diversity in science and engineering laboratories.

Recommendations from the literature to support SwD-P in STEM-based postsecondary programs include: 1) instructors collaborating with the student to identify techniques to allow full laboratory participation (e.g. setting up the laboratory experiments) [45]; 2) instructors evaluating critical laboratory activity functions and the student’s ability [38], [48]; 3) university support services (e.g. Disability Services) connecting instructors to programs or seminars that involve becoming more accustomed working with students with disabilities [20], [39], [44]; 4) instructors hiring full-time lab assistants for SwD [10]; 5) instructors modifying or repositioning equipment (e.g. relocate power strips) [16]; 6) and university support services (e.g. Career Services) and instructors supporting mentorship opportunities for the students outside the laboratory [38], [39], [44]. Moreover, additional research is required from the SwD-P perspective on accommodations used and needed for full participation.

Further investigation could advance SwD-P participation in STEM laboratories. Investigation of ground truth information directly from SwD-P and instructors to help uncover the barriers and facilitators surrounding STEM laboratories not found in the literature may help to understand the lack of access to full participation. Surveying stakeholders (e.g. instructors and SwD-P) to gather, confirm, and discover other barriers and facilitators that the literature may have not mentioned could also prove beneficial.

3.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: SURVEY DEVELOPMENT AND PSYCHOMETRICS

3.1 INTRODUCTION

In the U.S. there exists a shortage of educated, trained, and qualified candidates in STEM-oriented fields [2]. Contributing to the shortage is the lack of diversity within this field. For example, people with disabilities (PwD) remain underrepresented and underemployed in careers that focus on science and engineering (S&E). Despite adequate training [8], [10], [11], PwD only constitutes 7.2% of the S&E workforce [23]. According to the Bureau of Labor Statistics [27] physical disabilities are the most common impairment in the working-age group. Per this discussion, physical impairment is defined as those with upper and lower body limitations (e.g., difficulty walking, climbing stairs, grasping, lifting, pushing, pulling, sitting, standing, crouching, and reaching) [5], [6]. Thus, examining the barriers and facilitators that contribute to the lack of labor force participation among people with physical disabilities might help to address the shortage of these trained individuals in the S&E fields. Several viable approaches to determine the barriers and facilitators people with physical disabilities encounter in their everyday environments have been established through survey research [47], [49]. However, researchers have yet to address these same concerns for S&E access in postsecondary instructional science or engineering laboratory settings for students with physical disabilities.

For example, high quality commonly used surveys have been developed to subjectively assess participation of individuals with physical disabilities ranging from quality of life measures to level of activity participation in life’s events (e.g., Satisfaction with Life Scale (SWLS), World Health Organization Quality of Life-BREF scale (WHOQOL-BREF), Facilitators and Barriers Survey (FABS/M), Participation and Activities Screener (IMPACT-S), and Participation Measure for Post-Acute Care (PM-PAC)). These instruments were designed to gather information on the users' experience yet there is not an existing appropriate instrument designed specifically for postsecondary science or engineering laboratory settings that have been validated.

Each of these instruments has important limitations despite showing some evidence of psychometric properties. Both the SWLS and the WHOQoL-BREF assessed individuals with physical and cognitive disabilities life satisfaction. These surveys did not complete, an essential component to survey development, known as the content validity index (CVI) [50]. In particular, the SWLS, a five-item self-report survey focusing questions the individual’s holistic life’s satisfaction, did not complete content validity, and demonstrated poor to moderate reliability [51]. In contrast, the WHOQoL-BREF reported excellent reliability for the stability test, which may be large part due to the presence of interviewers who administered the survey, did not compute a content validation index [52]. Another significant issue is that this 26-item survey did not focus on any one particular environmental setting, but focused on the general working environment and social relationships [53]. The WHOQoL may be more beneficial for general working conditions but may be limited to identifying issues regarding a science or engineering laboratory.

Both the IMPACT-S and the FABS/M concentrate on the individual’s limitations in their everyday life environments concerning the activity and participation chapters of an established framework called the International Classification of Functioning, Disability, and Health (ICF). Post and colleagues [54], developed the 32-item IMPACT-S, which focused on limitations to activities and participation in general community environments. Although IMPACT-S’ reported good reliability [54] and had completed some content validation, the general environment warrants developing a new survey. Despite Gray and colleagues [49] focus on unspecified home and community environmental settings, the 133-item survey does specify its population to be individuals with lower limb impairments.

Similarly, the PM-PAC, focused specifically to individuals with physical impairments as well as developed based on the activities and participation chapters of the ICF. However, the 51-item survey focused on rehabilitation services in community-based settings and cannot directly apply to science and engineering laboratory environments [55].

These self-report subjective tools on assessing individuals with physical disabilities have provided some evidence of test-retest reliability, an essential component to survey development psychometric properties [56], [57]. Moreover, most of these authors provided some form of content validity but did not use conduct content validity index [50]. Subjective measures are more suitable to gather information from the user's perspective and experiences [51], [58]. While these subjective surveys provide insight into individual's experiences in their living environment, they are limited in scope; these surveys target general environmental barriers and facilitators, and they are not specific to postsecondary instructional science or engineering laboratory settings for students with physical disabilities.

A reliable and valid measure of full participation in instructional S&E laboratories would allow researchers and others to determine the barriers and facilitators students with physical disabilities might encounter in S&E laboratory environments. The ICF's taxonomy of participation and activities, describes the task and how the individual executes the task, serves as a critical component to help classify the barriers and facilitators of S&E laboratories [59]. Barriers are hindrances or factors that reduce participation, while facilitators are factors that promote or improve participation of students with physical disabilities in science laboratory settings [47], [59]. The research study described below subsequently aims to report on the development, initial content validation, and test-retest reliability towards developing a psychometrically sound measure that examines barriers and facilitators for students with physical disabilities using S&E laboratories.

3.2 METHODS

Survey items were generated and selected using common guidelines for survey development [56]. Critical factors were considered for item generation such as developing the items with an appropriate corresponding response format [56]. Items were generated based on some of the initial findings from a systematic literature review (discussed earlier in Chapter 2) and input from an initial set of experts in the field. Expert opinions came from two rehabilitation engineering graduate students with physical disabilities, two researchers in the field of rehabilitation, one able-bodied rehabilitation engineering graduate student and a professional engineer with a physical disability helped to revise the initial survey of over 100 questions. A professor at the University of Pittsburgh who designs surveys reviewed the survey for formatting but could not evaluate for content due to limited expertise in the area. Final items were determined (e.g. item selection) through both think-aloud sessions and content validity techniques using both experts and laypersons or persons who fit the target population [56]. Figure 2 outlines the stages of the survey development. Stage one involved generating items for the initial version of the survey using a literature review [59]. Stage two was a continuation of generating items by receiving input from an initial set of experts in multiple cycles for version two of this survey. Stage three started the item selection process using the think-aloud method with the target population judges. In stage four, items were selected and reviewed based on the content validity analysis using content validity index (CVI). The reliability portion of the study was approved by the University of Pittsburgh's Institutional Review Board approval.

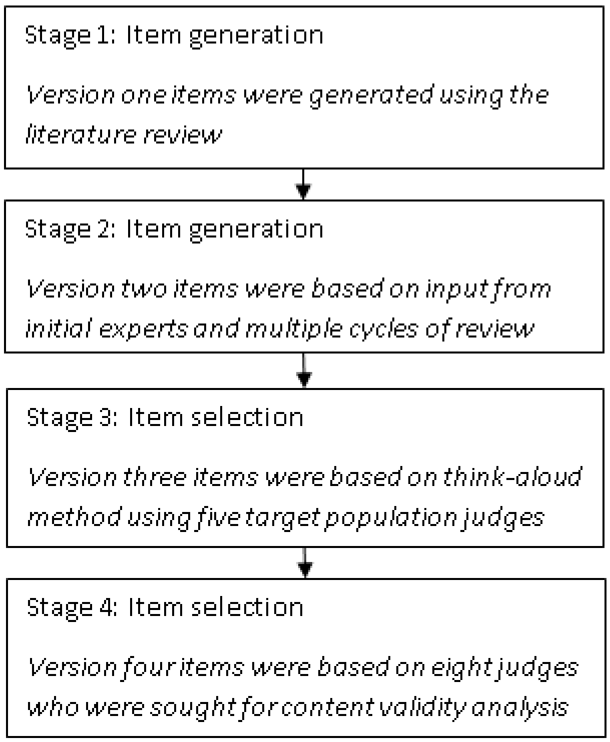

Figure 2. Stages of the Full Participation in Science and Engineering Accessibility Survey Development

3.2.1 Item Generation

3.2.1.1 Initial Survey Development

Initial item generation was conducted using information from an extensive literature review and binned into three defined content domain areas (with working definitions) using expert opinion: 1) the physical built environment of the S&E laboratory; 2) executing tasks within the S&E laboratory environment; 3) and the learning environment of the physical laboratory space [59].

The survey items included items adapted from pre-existing surveys and checklists. For example: attitudinal questions such as “Instructor(s) believe in most cases, it is best if peers conduct a science investigation with the student with the disability as an observer” were used in a survey [18], echoed in a checklist from the University of Washington’s DO-IT program, and formatted to a 5-point rating scale [60]. Other items that could not be adapted from existing checklists and surveys were generated from the literature. The following scale responses were used for each item where appropriate: dichotomous (YN), multiple selection (MRX), single selection or Likert (LK) 5-point scale response (i.e., *strongly agree (5) to strongly disagree (1)*).

After the first version of the survey was drafted on the Qualtrics online system, six individuals were consulted for survey revisions. These consultants provided expert opinions, reviewed survey items and made suggestions for item modifications or suggested additional survey items. After several revisions, the survey underwent item selection, which included think-aloud/ cognitive interviewing by five target population judges [56], [57]. The survey was further modified to reflect the input from these individuals and then underwent item level content validity index (I-CVI) to help complete a final draft of the survey.

3.2.2 Item Selection

3.2.2.1 Translational Validation

Content validity, helps ensure the survey is measuring what it is intended to measure [50]. Content validity was conducted by qualitative and quantitative methods used to determine whether the survey items represent the intended use by using target population and expert judges [56], [61].

3.2.2.2 Judges

The judges used in the content validity process helped to discern if the items belonged in the survey and content domains, in addition to remove and modify items by rating each question using the item-level content validity index (I-CVI) and providing written feedback. Four target population judges and four instructor judges were selected. Out of the 16 judges contacted through Human Engineering Research Laboratories contacts, eight judges were selected. Judges were selected on the following archetypes (with some overlap): 1) length of experience or familiarity working with students with physical impairments; 2) length of experience in a science or engineering laboratory; 3) length of experience or familiarity with disability research; 4) and length of experience teaching science or engineering. The surveys were revised based on the I-CVI calculations and feedback from the judges.

3.2.2.3 Think-Aloud Procedure

Cognitive approaches such as think-aloud sessions are becoming more prevalent among researchers and survey designers to help create a robust survey [62]. Think-aloud sessions are a way to verbalize thoughts while completing a task [63]. Think-aloud approaches have been used in clinical and other varied settings to understand cognitive processes [64]. The think-aloud approach was used in this study to help clarify questions on the survey. Five individuals from the target population (which included previous consultants for the survey) were selected for the think-aloud exercise. Each participant met with the survey developer individually for the think-aloud session. While completing the survey, the individuals were asked to describe their interpretation of the survey items. Notes were taken to revise the survey items. A follow-up session was conducted when comments were unclear.

3.2.2.4 Content Validity Procedure

All judges were given a form to rate each question based on the relevancy of the items and provide additional feedback (e.g. clarity, rewording). After the survey was completed during the think-aloud session, the student judges and instructor judges completed a 4-point rating scale for each question. The judges were able to provide written response for each question to make recommendations for improvement as part of the content validity process [50], [56], [57].

Judges were given a 4-point rating scale for each item in the Qualtrics online survey system [50], [65]. The scale ranged from 1 = not relevant, 2 = somewhat relevant, 3 = quite relevant, and 4 = highly relevant. All of the judges (i.e. including those that did not have a physical impairment) rated each question on a 4-point scale to ensure that the items represent the domains [56]. According to Lynn [50], a 4-point scale is best used when calculating the content validity index (CVI) [50]. Judges were informed that they could add a question they believed would be highly relevant and beneficial. Each judge was given the option to verbalize or write-up comments on specific items for the online survey when they submitted their ratings [56]. After the students completed the survey, all judges, provided feedback for each survey item.

3.2.2.5 Content Validity Analysis

The item-level CVI was computed to determine relevancy to the content area [50]. To calculate the CVI, the item was dichotomized and divided by the number of judges who completed the rating sheet [66]. Only items with a CVI of one were retained if there were five or less judges. However, because there were eight judges, a CVI of 0.78 was needed [50]. As for the qualitative component, judges were also able to write down feedback on any items of concern.

$$I_{CVI} = (number\ of\ experts\ giving\ ratings\ of\ 3\ or\ 4)/numberof\ experts \quad (1)$$

The judges rated each item on the 4-point scale to help reduce the survey items. For the quantitative ratings, the I-CVI threshold was 0.78 due to the number of judges [50]. Therefore, items that received an I-CVI less than 0.78 were removed from the survey. The qualitative feedback helped to inform the quantitative ratings on the 4-point rating scale. All comments were carefully considered. Additional experts reviewed the survey revisions for consensus. The scale-level S-CVI was calculated using the average method, which requires an index of 0.90 or higher for excellent content validity. The average method includes summing the I-CVIs and dividing by the number of items.

Rather than utilizing focus groups, the researcher considered survey feedback from each judge on an individual basis. In a focus group, participants may be reluctant to voice their opinions in front of others, also over dominance of a participant, which may influence the group discussion [67]. Obtaining feedback from each individual separately, gives the individual flexibility to freely express themselves reducing any concerns (e.g. overdominance and reluctance).

3.2.3 Test-Retest Reliability

The test-retest reliability of the survey consisted of a single cohort repeated-measures design. The intent of the survey was to get the past experience of students who completed a postsecondary instructional science or engineering laboratory course. Participants were screened using the following inclusion criteria: 1) having to be 18 or older; 2) have a physical disability; 3) have been or are currently enrolled in a technical school or college; 4) and have taken or are currently taking a Science, Technology, Engineering or Math (STEM) related course. As an incentive participates who completed the research study were entered into a drawing; 15 participants were randomly selected to win $35 using a random integer generator [68].

3.2.3.1 Participants

A total of 25 participants submitted the survey at two time points. Five respondents were removed from the analysis due to a combination of short time completion, lots of missing data throughout the survey and possible patterns of clicking through the data.

3.2.3.2 Test-Retest Procedures

Participants were recruited by contacting colleges and universities deans, disability service departments, advocacy groups, science and engineering companies across the country. Information about the purpose of survey was sent to them as well as additional information was provided to help disseminate the information throughout their institutions (i.e. *I am seeking your assistance in disseminating a survey to people who self-identify as having a physical disability within the (Name of school/your school) community*). The information sent also included the link for past and present students to access the online survey through any mobile device or web interface. The survey respondents were given a choice to decline or accept to take part in the retest of the survey. The survey was redistributed 10 to 14 days after the first submission. All data were collected through the online Qualtrics platform [69].

3.2.3.3 Data Analyses

To run the test-retest reliability analysis, the multiple selection response items and open-ended items were removed and only the Likert scale and dichotomous items were kept for analysis. Systematic biases during data analysis may be due to irregularities in missing data patterns [70]. Data were reviewed for patterns of data missing at random to reduce systematic biases in the data using Little's Missing Data Completely at Random (MCAR) test prior to reliability data analysis [71]. MCAR was not conducted for items missing less than 3 items, in which there would be too few missing points to compute. After completing the MCAR procedure, items with up to 20% missing data were imputed using mean value imputation [72], [73]. As the self-reported test-retest questionnaire data were not normally distributed, nonparametric Spearman correlation coefficients were calculated to measure relationship [57]. Spearman Rho were calculated for each imputed sub-item as well as the three domain areas built environment (BE), task execution (TE) and learning environment (LE). All imputed data were included, without removing outliers, which did not substantially vary the results. Even though the distributional assumptions were violated intra-class correlation coefficients (ICC) were also reported, using the two-way random effects models, absolute agreement, single trial estimate, ICC model (3,1) [74]. Additionally, the dichotomous items were calculated using chi-square and Fisher's exact test for items that had frequency count of less than five per cell [57]. Chi-square indicates whether the correlation between two dichotomous items are significant or independent of each other [57]. All statistical analyses were computed using IBM's Statistical Package for the Social Sciences (SPSS) version 24.0 [75].

3.3 RESULTS

3.3.1 Judges

A total of eight judges completed the 4-point rating sheet, one judge skipped two items in the TE category resulting in only 7 judges completing the rating form. The two items that only 7 judges critiqued both had an I-CVI of 0.86. Additional judges also gave written or verbal feedback which helped to modify and improve the quality of the items. Two judges from the target population were female and one female was in the instructor group. The remaining information on the judges' research expertise characteristics are located in Table 3.

Table 3. Length of Judges Expertise Characteristics

	Mean±SD [range] Years		
	Total	Target population Judges	Instructor Judges
Length of experience or familiarity with students with physical impairments	18.6±17.9 [7,60]	13.8±9.6 [7,28]	23.5±24.3 [10,60]
Length of experience with disability research	11.3±6.4 [2,23]	7.3±3.8 [2,10]	15.3±6.1 [8,23]
Length of experience in science or engineering laboratory	12.5±10.8 [4,35]	6.5±3.8 [2,10]	18.5±12.8 [7,35]
Length of teaching science or engineering experience	6.8±10.5 [0,30]	0.5±1 [0,2]	13±12.4 [1,30]

3.3.2 Content Validation of Survey Items

After the content validity, the survey was reduced to 80 survey items and additional demographics questions. The survey was further reviewed by experts for clarity and consensus. Table 4 provides the I-CVI for each item leading up to the version for distribution. Items with an I-CVI of 0.78 were kept while items below the threshold were removed. Also, Table 4 referenced the end result of the item, whether it was retained for use in the survey, and/or wording was improved based on feedback or deleted because it did not meet the threshold. The I-CVI of items kept ranged from (0.86 to 1). Using the S-CVI average method, the overall survey had an S-CVI of 0.94. Most of the qualitative feedback were considered for all items over the 0.78 threshold. The feedback was related to correcting grammar to improve wording and clarity of the items.

Table 4. Items and their I-CVIs used in the survey development

Ref.	***Category***	***Item Prior to I-CVI (survey item)***	***CVI***	***Amendments made***
1	BE	The route on the physical property of the main building's entrance (where the laboratory is located) had physical or information (e.g. entrance signage) barriers. (Q3.2)	1	Improved wording
2	BE	The entrance of the main building (which houses the laboratory) had physical barriers. (Q3.4)	1	Improved wording
3	BE	The entrance to the science or engineering laboratory had physical barriers exist**.** (Q3.6)	1	Improved wording
4	BE	The following were helpful to you when entering the laboratory space. Rate all that were present. If not present select "Not Applicable" (Q3.8)	1	Revised selections and added "other"
5	BE	The following were barriers to you when entering the laboratory space. Rate all that were present. If not applicable, select "Not Applicable." (3.10)	1	Improved wording
6	BE	You were able to enter the laboratory space despite any barriers. (Q3.12)	1	Unchanged
7	BE	There were physical barriers in maneuvering or getting around majority of the laboratory space (Q3.13)	1	Improved wording
8	BE	The following helped you access the laboratory environment. If not present select 'Not Applicable.' (Q3.15/Q3.17)	0.88	Improved wording, question split into two for appropriate selection choices
9	BE	Please list barriers in maneuvering or getting around the laboratory space.(Q3.19)	1	Unchanged

Table 4 (Continued)

Ref.	***Category***	***Item Prior to I-CVI (survey item)***	***CVI***	***Amendments made***
		~~You were able to access the laboratory space despite any barriers(Q3.20)~~	~~--~~	~~Later added~~
10	BE	When working in the laboratory all the necessary equipment were positioned close enough to allow you to complete the laboratory tasks. (Q3.21)	0.88	Improved wording
11	BE	The distance between workstations and laboratory equipment were positioned within your workcell to complete the laboratory tasks.	0.5	Removed
12	BE	The following safety procedures were addressed (e.g. arrangements were made for emergencies). If the situation did not apply to your laboratory experience, select "Not Applicable." (Q3.23)	0.88	Improved wording
13	BE	A simulated environment helped me to participate in the laboratory	0.125	Removed
1	TE	The majority of your participation in the laboratory was limited to which of the following activities:(Q4.2)	0.86	Improved wording
2	TE	The laboratory course materials (e.g. instructions and information) was accessible to help you participate in the laboratory activities (Q4.4)	0.88	Improved wording
3	TE	The laboratory activities helped you to get direct relevant experience in the laboratory	0.75	Removed
4	TE	You had experience physically setting up laboratory experiments or projects	0.75	Removed
5	TE	There were physical barriers in setting up laboratory experiments or projects (Q4.6)	1	Unchanged
6	TE	There was enough time allotted to setup laboratory experiments or projects (Q4.8)	0.86	Improved wording

Table 4 (Continued)

Ref.	***Category***	***Item Prior to I-CVI (survey item)***	***CVI***	***Amendments made***
7	TE	You had experience physically operating laboratory equipment	0.75	Removed
8	TE	There were physical barriers to operating laboratory equipment to perform laboratory tasks (Q4.10)	1	Changed to 5-point scale
9	TE	Laboratory equipment were modified or manipulated so you could complete a laboratory Task (Q4.12)	0.88	Improved wording and added selection choice to the dichotomous question
10	TE	The following were helpful to using the laboratory. Select 'Not Applicable' if it did not apply to your situation: adjusting size of wheels, etc.	0.5	Removed
11	TE	The following were helpful (if you had access) to operating the laboratory equipment. Select 'Not Applicable' if the situation did not apply. (Q4.14)	1	Split selections to BE & TE
12	TE	The following are true statements about the laboratory equipment. Select 'Not Applicable' if the situation does not apply. (Q4.16)	1	Unchanged
13	TE	Please list any assistive technology that helped you to complete laboratory tasks (Q4.18)	1	Unchanged
14	TE	You were able to use tools and other laboratory materials (Q4.19)	0.88	Improved wording
15	TE	Please rate how much you agree with the statements in handling laboratory tools and equipment (Q4.21)	0.88	Improved wording
16	TE	Please rate how much you agree with the statements in handling laboratory tools and equipment	0.75	Removed
17	TE	Check all the material that were made available	0.5	Removed

Table 4 (Continued)

Ref.	***Category***	***Item Prior to I-CVI (survey item)***	***CVI***	***Amendments made***
18	TE	Laboratory equipment were accessible without modifications to complete laboratory equipment	0.5	Removed
19	TE	You were able to physically participate in the laboratory despite any barriers	0.75	Removed
1	LE	Q4.2 The laboratory environment felt welcoming.	0.71	Removed
2	LE	To what extent do you agree with these statements regarding instructors or laboratory assistants while working in the laboratory space (Q2.4)	0.88	Unchanged
3	LE	Lab partners helped in completing laboratory tasks	0.75	Removed
4	LE	Lab partners made accessing the laboratory difficult	0.38	Removed
5	LE	Assistance from colleagues and able-bodied peers (e.g. non-lab partner) helped in completing laboratory tasks (Q2.6)	0.88	Unchanged
6	LE	Assistance from colleagues and able-bodied peers (e.g. non-lab partner) made accessing the laboratory difficult	0.57	Removed
7	LE	Instructor(s) or laboratory assistant(s) were willing to accommodate to your specific Needs (Q2.8)	0.88	Unchanged
8	LE	Instructor(s) believe in the most cases, it is best if peers conduct a science investigation with the student with disability as an observer (Q2.10)	0.88	Unchanged
9	LE	Instructor(s) believe it is unreasonable to expect science laboratories to be open extra hours to allow the student with	0.75	Removed

Table 4 (Continued)

Ref.	*Category*	*Item Prior to I-CVI (survey item)*	*CVI*	*Amendments made*
		disability extra time for lab investigations		
10	LE	Instructor(s) believe it is impossible to expect a student with a physical disability to be an active participant in all science laboratory exercises	0.63	Removed
11	LE	Programs were available to help instructors be equipped and be better prepared to teach students with disabilities (Q2.12)	0.88	Response format: added unknown as a selection choice to 5-point scale due to expert recommendation
12	LE	Please list programs that you are aware of to help instructors better prepare to assist students with disabilities	0.5	Removed
13	LE	Which would help instructors or laboratory assistants? Check all that apply.	0.75	Removed
14	LE	What areas were beneficial for you (in your experiences after high school)? Check all that apply	0.42	Removed
15	LE	Who most helped you in fully participating in the laboratory? Check all that apply (Q2.2)	0.88	Unchanged

3.3.3 Survey Final Draft

After reviewing the literature, revising the survey through expert opinion, completing think-aloud sessions, and conducting content validation; the Full Participation in Science and Engineering Accessibility (**FPSEA**) survey was created. The questionnaire generally asks about participants science and engineering laboratory experience and general demographic questions such as year of birth, year of acquired injury, diagnosis, level of ability, and school they attended. The questionnaire consisted of approximately 110 sub-items, with 30 demographic and screening sub-items and the remaining questions were organized in blocks as shown in Table 5. A 5-point rating scale format was primarily used, and the other three response formats were appropriate. The Likert (LK) 5-point scale response ranged from strongly agree (5) to strongly disagree (1), examples are shown in Table 6. One item was an exception that required "no modification" as an additional response choice to the dichotomous question (Q4.12).

Table 5. Survey Item Breakdown

Category type					
Physical architecture of the laboratory space (BE)					
Executing tasks in the laboratory space (TE)					
Learning environment (e.g. interaction between student and instructor) (LE)					
Item type					
Dichotomous (YN)					
Multiple selection response (MRX)					
Likert-scale (LK)					
Open-ended (OE)					
Number of sub-items by category	**Total**	**YN**	**LK**	**OE**	**MRX**
BE	43	15	27	1	0
TE	26	2	22	1	1
LE	12	0	11	0	1

Table 6. FPSEA Survey Response Scale

Category	Items	Response Options
BE	Q3.6 There were physical barriers to the entrance of the science or engineering laboratory. ● Yes ● No	*Dichotomous*
TE	Q4.2 Was the majority of your participation limited to any of the following activities? Check all that apply. ● Note-taking ● Writing papers ● Programming software ● Was not limited ● Other	*Multiple Selection Response*
LE	Q2.4 To what extent do you agree with the following statements regarding instructors or laboratory assistants while working in the laboratory space. ● Had knowledge in how to accommodate students with disabilities ● Practices were in place to accommodate students with disabilities ● Inclusive behavior ● Respectful and inclusive language ● Instructors encouraged student's abilities ● Instructor(s) worked with student to make accommodations ● Other	*Likert* *(Strongly agree to strongly disagree)*

3.3.4 Reliability

3.3.4.1 Missing Data Analysis and Demographics

The survey has a total of 80 sub-items. Due to the branching logic in the survey, a participant can view at least 62 and up to 72 items. A total sample of 25 individuals completed the retest. Missing data analysis was computed on the 25 individuals. Each item passed Little's MCAR test ($p>0.05$), indicating there are no irregular missing data patterns and the data can be imputed for analysis [71]. The results were approximately similar when treating the non-applicable responses as nonresponses (Table 7 and Table 8). After removing five participants from the analysis, data were imputed on the 20 remaining individuals.

Table 7. MCAR Test Results (n=25) include N/A option

MCAR Test Results (n=25) for each domain, sub-items include N/A option			
Sections (6's included)	MCAR Test p-value (# items)	(Respondents missed 1+ sub-items)	(Respondents missed all sub-items)
T1 Q2.x	0.4 (11)	(3) skipped Q2.4_6	(1) Skipped All
T2 Q2.x	0.44 (11)	(5) skipped Q2.4_6	(0) Skipped All
T1 Q3.x	no missing (5)		(0) Skipped All
T2 Q3.x	0.384 (5)	(1 missed T2Q3.21)	(0) Skipped All
T1 Q3.8	0.702 (6)	(11) missed 1+	(7) Skipped All
T2 Q3.8	0.067 (6)	(10) missed 1+	(8) Skipped All
T1 Q3.10&Q3.12	0.563 (7)	(19) missed 1+	(18) Skipped All
T2 Q3.10&Q3.12	0.409 (7)	(19) missed 1+	(17) Skipped All

Table 7 (Continued)

MCAR Test Results (n=25) for each domain, sub-items include N/A option			
Sections (6's included)	MCAR Test p-value (# items)	(Respondents missed 1+ sub-items)	(Respondents missed all sub-items)
T1 Q3.15YN	0.472 (9)	14) missed 1+	(12) Skipped All
T2 Q3.15YN	0.989 (9)	(15) missed 1+	(13) Skipped All
T1 Q3.17,Q3.23 LK	0.585 (15)	(8) missed 1+	(1) Skipped All
T2 Q3.17,Q3.23 LK	0.703 (15)	(4) missed 1+	(0) Skipped All
T1 Q4.X	0.656 (22)	(2) missed Q4.14_13	(1) Skipped All
T2 Q4.X	0.391 (22)	(3) missed Q4.14_14, (1) missed Q4.14_7	(0) Skipped All
T1 Q4.12 & Q4.19	cannot compute	T1 (1) missing	T2 (0) missing

Legend:

LE Domain
BE Domain
TE Domain

Table 8. MCAR Test Results (n=25) N/A option as missing data

MCAR Test Results (n=25) for each domain, sub-items considers N/A option as missing data			
Sections (6's excluded)	MCAR Test p-value (# items)	(Respondents missed 1+ sub-items)	(Respondents missed all sub-items)
T1 Q2.x	0.178 (11)	(10) missed Q2.12, (3) missed Q2.4_6 (other) or Q2.12	(1) Skipped All

Table 8 (Continued)

MCAR Test Results (n=25) for each domain, sub-items considers N/A option as missing data			
Sections (6's excluded)	MCAR Test p-value (# items)	(Respondents missed 1+ sub-items)	(Respondents missed all sub-items)
T2 Q2.x	0.463 (11)	(11) missed Q2.12, (5) missed Q2.4_6 or Q2.12	(0) Skipped All
T1 Q3.x	0.650 (5)	1 missed Q3.21	(0) Skipped All
T2 Q3.x	0.384 (5)	1 missed Q3.21	(0) Skipped All
T1Q3.8	0.712 (6)	(23) missed 1+	(8) Skipped All
		(10) missed Q3.8_2	
T2 Q3.8	0.979 (6)	(25) missed 1+	(8) Skipped All
		(8) missed Q3.8_2 and Q3.8_12	
T1 Q3.10&Q3.12	0.969 (7)	(19) missed 1+	(0) Skipped All
T2 Q3.10&Q3.12	0.928 (7)	19 missed 1+	(17) Skipped All
T1 Q3.15YN	0.521 (9)	(23) missed 1+	(12) Skipped All
T2 Q3.15YN	1.00 (9)	(25) missed 1+	(13) Skipped All
T1 Q3.17,Q3.23 LK	0.995 (15)	(24) missed 1+	(0) Skipped All
T2 Q3.17,Q3.23 LK	0.854 (15)	(24) missed 1+	(0) Skipped All
T1 Q4.X	0.915 (22)	(24) missed 1+	(1) Skipped All
T2 Q4.X	0.998 (22)	(24) missed 1+	(0) Skipped All
T1 Q4.4-4.10, Q4.21	0.846 (6)	(7) missed 1+	(1) Skipped All
T2 Q4.4-4.10, Q4.21	0.055 (6)	(7) missed Q4.21	(0) Skipped All
T1 Q4.14	0.724 (11)	(24) missed 1+	(7) Skipped All
T2 Q4.14	0.990 (11)	(25) missed 1+	(6) Skipped All
T1 Q4.16	0.714 (5)	(15) missed 1+	(3) Skipped All

Table 8 (Continued)

MCAR Test Results (n=25) for each domain, sub-items considers N/A option as missing data			
Sections (6's excluded)	MCAR Test p-value (# items)	(Respondents missed 1+ sub-items)	(Respondents missed all sub-items)
T2 Q4.16	0.885 (5)	(18) missed 1+	(3) Skipped All
T1 Q4.12 & Q4.19	cannot compute		

The median survey completion time was 18.4 minutes (time 1) and 13.9 minutes (time 2). The average standard deviation and range of the survey completion time were 255.3 ± 1029.7 [9.0,4628.9] minutes and 13.9, 316.7 ± 993.6 [6.7, 4293.8], at time 1 and time 2, respectively. One survey respondent took 4293.8 minutes (3 days) to complete the survey, this due to leaving the survey and completing at a later time, as shown in Table 9. The 20 participants' demographic characteristics are shown in Table 10. The majority of the respondents in the sample were female (65%), had difficulty bending, kneeling, squatting or crawling without assistance (65%), and were pursuing a postsecondary degree (55%) at the time.

Table 9. Test-Retest Duration Times (n=25)

Test-Retest (n=25) Duration of washout period, test, retest			
ID	Retest (Days)	T1 Min	T2 Min
1	10.9	20.2	6.9
2	10.9	80.9	171.4
3	14.0	9.0	12.9
4	12.1	20.5	21.4
5	11.0	8.1	14.7
6	9.6	4628.9	77.2
7	10.5	11.2	7.8
8	13.0	22.0	37.5

Table 9 (Continued)

Test-Retest (n=25) Duration of washout period, test, retest			
ID	Retest (Days)	T1 Min	T2 Min
9	9.8	5.9	2.9
10	10.1	13.0	17.1
11	11.1	17.3	8.7
12	9.0	17.2	8.7
13	12.3	18.7	9.0
14	9.6	71.6	6.7
15	10.1	11.9	9.7
16	7.8	11.3	8.5
17	10.1	14.9	9.0
18	10.3	17.5	18.3
19	9.0	11.7	1508.6
20	9.9	64.2	4293.8
21	10.7	14.9	10.0
22	12.7	8.5	5.6
23	12.9	21.4	23.1
24	10.8	18.1	14.9
25	9.9	19.6	68.6

Table 10. Test-Retest Reliability (n=20) Descriptives on Duration

Test-Retest Reliability (n=20) Descriptives Duration of washout period, test, and retest		
N=20 Retest (Days)	T1 Min	T2 Min
Median, Mean ± SD [range]		
10.4, 10.7 ± 1.5[7.8,14.0]	18.4, 255.3 ± 1029.7 [9.0, 4628.9]	13.9, 316.7 ± 993.6 [6.7, 4293.8]

3.3.4.2 Test-Retest Results: Likert Domain, Likert Item-level, and Dichotomous

Reliability was computed for Likert scale and dichotomous items (Table 11- Table 13). A total of 24 questions were computed for test-retest. For the Likert-scale sub-items: six Built Environment (BE), nine Task Execution (TE), and nine Learning Environment (LE) sub-items were computed. Additionally, seven dichotomous items were calculated. As mentioned previously in the data analysis section, items were only imputed if there was up to 20% missing data. The remaining items were not computed if items at both time points had over 20% missing data for the retest reliability assessment. As a result, reliability cannot be reported for these items**.** Domain level reliability was computed for Built Environment (BE) (Spearman Rho = 0.626), Task Execution (TE) (Spearman Rho = 0.573), and the Learning Environment (LE) (Spearman Rho = 0.846). At the item-level test-retest reliability, at least seven items had the largest correlation values (>0.70), ten items had correlation values between 0.50-0.70, and up to 7 items had the lowest values (<0.50), two sub-items from BE, four sub-items from TE, and one sub-item from LE. The item-level Spearman values were also reported because each item is unique and can provide different insight to specific laboratory situations.

Table 11. Item-Level Test-Retest Reliability Results

Item-Level Test-Retest Reliability Results of ICC Calculation in SPSS Using Single-Rating, Absolute-Agreement, 2-Way Mixed-Effects model, Pearson and Spearman Rho.					
		95% Confidence Interval			
Item #	ICC	Lower Bound	Upper Bound	Pearson	Spearman Rho
*LE_Frs_KnowldgAccom [Q2.4_7]	0.313	-0.126	0.654	0.316	0.31
LE_Frs_PracticesAccom [Q2.4_2]	0.682	0.349	0.862	0.673	0.661
LE_Frs_InclBehav [Q2.4_3]	0.782	0.527	0.908	0.776	0.776
LE_Frs_Language [Q2.4_4]	0.877	0.715	0.949	0.877	0.817
LE_Frs_Encourage [Q2.4_5]	0.745	0.456	0.891	0.768	0.739
LE_Frs_WorkedToAccom [Q2.4_1]	0.853	0.667	0.939	0.85	0.843
LE_Frs_Other [Q2.4_6] 33% missing rate (mr)					
LE_Frs_ColleaguesAssist [Q2.6]	0.701	0.384	0.87	0.708	0.625
LE_Frs_WillingAccom [Q2.8]	0.745	0.466	0.89	0.752	0.773
LE_Brs_Observe [Q2.10]	0.6	0.217	0.821	0.588	0.559
Q2.12 (not computed) - missing 13					
Q4.2 (not computed)					
*TE_Frs_CourseMaterial [Q4.4]	0.4	-0.037	0.709	0.398	0.56
TE_Brs_LabSetup [Q4.6]	0.387	-0.062	0.704	0.391	0.357
TE_Frs_TimeAllotted [Q4.8]	0.64	0.285	0.84	0.634	0.604
NEW_TE_Brs_OperateEqpt[Q4.10]	0.138	-0.341	0.546	0.137	0.262
TE_Frs_EquipModified [Q4.12] - YN					
Q4.14 (not computed) -					
TE_Frs_CntrlsFrmSeat [Q4.16_1] 20%mr	0.601	0.228	0.82	0.599	0.55
TE_Frs_OppKnobs [Q4.16_2] - 33%mr					
TE_Frs_Grasping [Q4.16_3] - 20%mr					
TE_Frs_Force [Q4.16_4] - 20%mr					
TE_Frs_AssistTech [Q4.16_5] - (not computed)					
TE_Frs_IndpTools [Q4.19] - YN - missing[10-20]					
TE_Brs_DiffGrasp [Q4.21_1] 20%mr	0.563	0.161	0.802	0.557	0.518
TE_Brs_DiffSlip [Q4.21_2] 20%mr	0.516	0.112	0.775	0.515	0.5
*NEW_BE_Brs_Info [Q3.2] YN					
NEW_BE_Brs_MainBldg[Q3.4] YN					
NEW_BE_Brs_LabEntrance[Q3.6] YN					
q3.8 missing [7-18]					
BE_Frs_OppDoor [Q3.8_6] - missing 8					
q3.10 missing [13-20]					
q3.12 missing 13					

Table 11 (Continued)

Item-Level Test-Retest Reliability Results of ICC Calculation in SPSS Using Single-Rating, Absolute-Agreement, 2-Way Mixed-Effects model, Pearson and Spearman Rho.					
		95% Confidence Interval			
Item #	ICC	Lower Bound	Upper Bound	Pearson	Spearman Rho
q3.13 YN					
Q3.15 YN missing [10-13]					
BE_Frs_Aisle [Q3.17_10] 20%mr	0.464	0.024	0.75	0.452	0.452
BE_Frs_PwrStrip [Q3.17_13] 20%mr	0.659	0.324	0.849	0.666	0.674
BE_Frs_Drawers[Q3.17_11] 33%mr					
BE_Frs_Sink [Q3.17_4] 20%mr	0.779	0.52	0.907	0.777	0.763
BE_Frs_AdjTable[Q3.17_3] missing 8					
BE_Frs_RaisedPltform[Q3.17_2] missing 12					
BE_Frs_LowShelf[Q3.17_1] missing 11					
BE_Frs_Ramp [Q3.17_12] missing 11					
BE_Frs_Other[Q3.17.9] missing 19					
BE_Frs_AccessBldg[q3.20] YN missing 10					
BE_Frs_LabEquipPosition [Q3.21] YN 10%mr					
BE_Frs_EmrgExit [Q3.23_1] 20%mr	0.598	0.228	0.818	0.64	0.662
BE_Frs_Eyewash [Q3.23_13] 20%mr	0.67	0.32	0.857	0.722	0.747
BE_Frs_Hazardous [Q3.23_14] 20%mr	0.089	-0.368	0.506	0.088	0.267
BE_Frs_ShowerPull [Q3.23_12] 33%mr					
BE_Frs_AltEmerg [Q3.23_15] 33%mr					
BE_Frs_Other [Q3.23_5] missing 19					

*Built Environment (BE) Domain; *Task Execution (TE) Domain; Learning Environment (LE) Domain; *Lowest rated items (<0.50). Cells are left blank intentionally.

Table 12. Domain Level Test-Retest Reliability Results

Domain Level Test-Retest Reliability Results of ICC Calculation in SPSS Using Single-Rating, Absolute-Agreement, 2-Way Mixed-Effects model; Pearson and Spearman Rho						
		95% Confidence Interval				
Domain	ICC	Lower Bound	Upper Bound	Pearson	Spearman Rho	# of Sub-Items Computed
***BE**	0.699	0.392	0.868	0.715	0.626	6
***TE**	0.563	0.163	0.802	0.584	0.573	9
***LE**	0.928	0.828	0.971	0.932	0.857	9

*Built Environment (BE) Domain; *Task Execution (TE) Domain; Learning Environment (LE) Domain; *Lowest rated items (<0.50).

Chi-square was computed for the seven dichotomous variables. For items with low frequencies in some cells, Fisher's exact were computed (Table 13); all except one had significance ($p<0.05$). For the dichotomous variable, only the question regarding the main building's entrance did not meet the Fisher's exact test. Nonetheless, because, there was 80% agreement between both time points, we considered the results for this item to be reasonable. One of the BE items ("*There were physical barriers in maneuvering or moving around the majority of the laboratory space*") did not meet the requirements for Fisher's exact test, but had 75% agreement, with only five respondents who switched answers between exams. Another item in TE ("*Laboratory equipment was modified so that you could complete a laboratory task*") had three selection responses (Yes, No, No modifications were needed) which produced a 3-by-3 table, with this there were only 70% agreement between answers. The seven items with the lowest retest results, had lower agreement (ranged from 35-65%), and still seemed reasonable.

Table 13. Item-Level Test-Retest Reliability Results in SPSS for dichotomous data

Item-Level Test-Retest Reliability Results in SPSS for dichotomous data (Chi-Square, Fisher's)		
Item (YN)	Pearson Chi-Square (DoF); Fisher's Exact	Descriptive Notes (% agreement between Time1 and Time2)
ǂNEW_BE_Brs_Info [Q3.2] YN	χ^2 (1) =7.213, p=0.007; p=0.017	80% exact agreement between 2 timepoints
ǂNEW_BE_Brs_MainBldg[Q3.4] YN	χ^2 (1)=4.821(1), p=0.028; p=0.061	80% exact agreement between 2 timepoints
ǂNEW_BE_Brs_LabEntrance[Q3.6] YN	χ^2 (1) = 9.377, p<0.002; p=0.004	85% exact agreement between 2 timepoints
ǂQ3.13 YN	χ^2 (1) = 5.051, p=0.025; p=0.07	75% exact agreement between 2 timepoints, 5 switched responses
ǂBE_Frs_LabEquipPosition [Q3.21] YN	χ^2 (1) = 8.571,p=0.003; p=0.011	80% exact agreement between 2 timepoints; 4 switched responses
ǂTE_Frs_EquipModified [Q4.12] - YN	χ^2 (4)= 11.417, p=0.022;	3x3 table, χ^2 may not apply, 70% exact agreement between timepoints
ǂTE_Frs_IndpTools [Q4.19] - YN	χ^2 (1) =13.388,p<0.001; p<0.001	90% of the cells have exact agreement between timepoints
ǂ Fisher's test are reported for items with cells less than 5 responses		

3.3.4.3 Lowest Reliability

Seven items appeared to be the least stable between both time points (Table 14). The four items in TE that performed the lowest included: 1) setting up laboratory experiments (Spearman=0.357); 2) operating laboratory equipment (Spearman=0.262); 3) hand controls of equipment (Spearman=0.096); 4) and equipment operable without large force (Spearman=0.310). The two items in BE with the lowest performance was one on safety measures for handling hazardous materials (Spearman=0.267) and aisles cleared for ease of laboratory use (Spearman=0.452). The only item in LE with the lowest reliability rating was concerned with instructors or laboratory assistants "*Had knowledge in how to accommodate students with disabilities*" (Spearman=0.313), which may indicate that may not easily perceive instructors' knowledge on how to accommodate students with disabilities.

Most of the lowest reliability items came from TE (4) which resulted in a TE as the lowest repeatability out of all three domains. The lowest items in TE included 1) setting up laboratory experiments or projects (Spearman rho =0.357); 2) operating laboratory equipment (Spearman rho =0.262); 3) hand controls of equipment operable without fine motor skills (Spearman rho =0.096); 4) and equipment was operable without large force (Spearman rho =0.310). Although the Spearman measure did not favor the four items in TE, the two items were among the highest in agreement (e.g., "Strongly Agree-Strongly Agree"), selecting the same response at test and retest. More respondents had agreement or changed their responses by one item selection (e.g., "strongly agree - somewhat agree"), than those changing their responses by two or more item selections at retest (e.g., "strongly agree - somewhat disagree"). The item about laboratory setup had 65% agreement with only one respondent who changed his or her item responses. The item on operating laboratory equipment had a little less agreement (55%) with more individuals changing their responses by two or more selections from their initial choice (20%). This much change can help to explain the lower reliability value. The remaining two TE items with 20% missing data had 40% agreement and up to 35% of respondents changing their responses by two selections during retest.

Table 14. Seven sub-items that performed the lowest reliability

Seven sub-items that performed the lowest reliability	
7 Lowest Likert sub-items	Sub-item (Spearman)
LE_Frs_KnowldgAccom [Q2.4_7]	To what extent do you agree with the following statements regarding instructors… Had knowledge in how to accommodate students with disabilities (0.31)
BE_Frs_Aisle [Q3.17_10]	The following made it easy to use the laboratory space… Aisles cleared (0.452)
BE_Frs_Hazardous [Q3.23_14]	The following safety procedures were addressed in the laboratory environment (e.g. arrangements were made for emergencies)… Safety measures for handling hazardous materials (0.267)
TE_Brs_LabSetup [Q4.6]	There were physical barriers in setting up laboratory experiments or projects (0.357)
TE_Brs_OperateEqpt[Q4.10]	There were physical barriers to operating laboratory equipment to perform laboratory tasks (0.262)
TE_Frs_Grasping [Q4.16_3]	Hand controls of equipment operable without tight grasping, pinching, or twisting of the wrist (0.096)
TE_Frs_Force [Q4.16_4]	Equipment operable without large force (0.310)

3.4 DISCUSSION

This study provides sufficient evidence for content validity and adequate evidence for test-retest reliability of the FPSEA Survey. Currently, there is a need for an appropriate survey that specifically examines the barriers and facilitators students with physical disabilities (SwD-P) experience within postsecondary science or engineering instructional laboratory settings. The FPSEA Survey fills this gap. Overall the survey had good content validity and moderate to excellent test-retest reliability. Within the discussion section are two major sections: content validity and reliability. The content validity section is organized into the following domains: 1) the physical built environment of the S&E laboratory; 2) executing tasks within the S&E laboratory environment; 3) and the learning environment of the physical laboratory space. The test-retest reliability portion is organized in a similar fashion.

3.4.1 Content Validity

The development and content validation of the final 80-item version of this survey were reported in this article. The I-CVI items that met the threshold had values from 0.86 and above and the S-CVI above 0.90, suggested that there was excellent content validity. Maximizing the involvement of key stakeholders was critical in the development and refinement of the survey items. Using judges from the target population who also have a number of years of experience in several archetypes, provided insight to ensure the survey items were appropriate for each content area using the mixed-methods approach to help refine and validate the survey.

3.4.1.1 BE Content Validity

To reiterate, the BE section pertains to the physical structure of the environment; the LE section reflects the soft skills and attitudes. Moreover, TE pertains to the actual function and use of the laboratory space, which other surveys have not addressed. The built environment (BE) section represented most of the items (14) in the survey. This imbalance of items in this area corresponds to the extensive literature found in this area [11], [14], [20], [21], [35], [40], [41], [43], [46], [76]. As reported by the I-CVI, most of the judges agree that the questions were relevant to this critical topic and only two questions were removed because they did not believe it was as relevant to the topic or needed extreme clarification which would change the entire item altogether. For example, regarding the item "*A simulated environment helped me to participate in the laboratory,*" many judges believed this should be removed or there should be a clear definition of what simulated environment means.

3.4.1.2 TE Content Validity

The task execution (TE) domain had the next most represented items (11) in the survey. This number similarly corresponds to the articles found in the Jeannis et al. [59] literature review related to TE barriers [16], [21], [25], [26], [36]–[38], [40], [41], [44], [76]. Approximately eight questions were removed. Questions from TE were removed that did not meet the threshold because judges believed the: 1) item was not needed; 2) all of the selection choices (or sub-items) were highly relevant in another domain; 3) or too general or unrelated to the topic.

3.4.1.3 LE Content Validity

The learning environment (LE) of the physical space domain, had fewer items (6) in the survey because it has less to do with the use of the laboratory. The LE set of questions were related to the attitudes of instructors and peers. Although a substantial amount of literature exists on the topic of attitudes, and that most of the items were gleaned from the literature, the majority of the judges rated these items low. Approximately nine questions were removed based on the judges' concerns about the questions being too confusing, ambiguous, or not applicable to the target audience or irrelevant.

Two questions that met the threshold had only seven responses, and both were in TE. Two questions met the threshold "*There was enough time allotted to setup laboratory experiments or projects*" and the other was "*The majority of your participation in the laboratory was limited to which of the following activities.*" Although these questions meeting the threshold to be included in the survey, the judges gave input for better word choice and pointed out that the selection choice was forced to one possible answer instead of multiple possibilities. The researcher later modified the question by changing the single choice response into a multiple-choice response possibility.

Other questions that did not meet the threshold with only seven responses capped at I-CVI=0.71, which would not make a difference, because if the eighth person gave them the highest rating, the score would still be insufficient (I-CVI=0.75). The judges continued to provide additional feedback to improve the wording, even items with a high rating. For example, two judges, one from each side, the target population judge and the instructor judge, who marked the question on " *the majority of your participation*..." as high relevancy (4), gave input on how the wording could be improved.

3.4.2 Test-Retest Reliability

The BE domain which consisted of 6 items had moderate to high repeatability (Spearman rho =0.626). As expected this finding was consistent with the amount of literature made available on the topic [16], [24], [26], [33], [77]. Since the enactment of the ADA, Americans with Disabilities Act Accessibility Guidelines (ADAAG), were developed and other research have progressed over the years to help facilitate reasonable accommodations entering buildings and facilities, helped shape to the items that were already used in BE [37], [78].

Aggregating the nine computed items from the TE section produced a moderate reliability (Spearman rho=0.573). The LE domain produced the highest reliability (Spearman rho 0.857) with nine items. This high reliability may speak to the large amount of existing literature related to attitudes of instructors that helped to guide the items used in the survey [35], [40], [41], [43], [46].

Only one item in the LE domain was among the seven items with lowest reliability, regarding instructor’s knowledge in accommodating SwD-P from the student’s perspective (Spearman rho = 0.31). This is confirmed in the literature related to leisure activity, life satisfaction, and pain which is difficult to capture repeatability and thus do not often have high reliability scores [51].

The two items in BE with the lowest reliability include: 1) aisles being cleared to making that laboratory easier to use (Spearman rho =0.45); 2) safety measures procedures were addressed for handling hazardous materials (Spearman rho =0.267). One-third of the items in BE ended up having the lowest reliability may have resulted in a lower overall reliability for BE. However, this value is still deemed as an acceptable reliability value [79]. Removing or modifying items that have been reported as least stable (Table 14) may improve the reliability performance in each of the domain areas, nonetheless, items with to the larger percentage agreement were still be deemed considered reliable.

Despite the reluctance of the respondents to provide written feedback, few respondents who provided written feedback, provided the feedback that was insightful. One out of the eighteen participants who opted to leave written feedback mentioned both that the aisles were clear, yet they could not fit through the aisles to use the equipment. Another participant regarding operating laboratory equipment mentioned visual difficulties using the microscope during the first test, and at retest mentioned difficulty with manipulating small objects and pouring chemicals. Because the participant did not mention the same barrier, there may be recall bias for certain questions. Participants may have recalled a different laboratory experience situation during some items on the retest.

The results of the FPSEA Survey study share similar results to other established self-report studies. Other self-report studies have reported Spearman on an individual's physical activity, with reliability correlations between 0.34 to 0.89 [79] and 0.46 to 0.96 [80]. The FPSEA Survey produced similar results correlation ranging from 0.57 to 0.86 at the domain-level. The FPSEA Survey's smallest correlation was similar Salis and Saelens' [79] acceptable minimum (Spearman=0.60). Other self-report studies that reviewed the barriers and facilitators to people with physical disabilities reported interclass correlation coefficients and Pearson's *r* instead of Spearman's correlation coefficient [49], [51].

Previous self-report subjective studies on participation of individuals with physical disabilities have mainly reported intra-class correlation coefficients (ICC). Given the parametric assumptions, the results suggest that the FPSEA Survey is comparable to similar participation surveys. The SWLS survey on life satisfaction found poor to moderate reliability on people with spinal cord injury (ICC=0.39 to 0.65) [51]. The Impact-S and WHO-QoL reported moderate to excellent repeatability (ICC= 0.54 to 0.98) [53], [54]. Au contraire, the FABS/M which was closest to our study only reported Pearson's correlation coefficient on a sample size of 371, had a moderate to excellent test-retest reliability (0.52 to 0.81). Nonetheless, these results were similar to the FPSEA Survey. As such, the overall similarities confirm the FPSEA Survey can be used to assess SwD-P participation in postsecondary instructional science or engineering laboratory settings.

3.4.3 Limitations

This study has its limitations in that the content validity of the survey only went through one iteration and the judges were not consulted in a group setting. The single iteration of content validity helped to reduce the number of items and the individual feedback from judges helped to reduce influences of opinions from other judges. Most people are familiar with using computers and mobile devices (e.g. smartphones), this study was primarily suited to meet the needs of those who have electronic access to a mobile device with internet capabilities, which should be considered when interpreting the results. Students who could not afford access to this technology or whose physical disabilities prevented them from accessing the survey were not included. Hence, their perspectives were not represented.

Moreover, when filling out the survey the study requires ability to enter responses and select ratings on a scale for most items. If the respondent does not have the physical ability to do so, it was up to the user to ensure the appropriate assistive technology or software was installed on their machine (e.g. Dragon NaturallySpeaking) to respond to the survey questions. Nevertheless, the survey is 508-compliant, and the online platform makes it user-friendly and adaptable to meet the needs of various physical disabilities. The small sample size for test-retest may have impacted our data analysis, where other studies used reliability sample sizes larger than 100 participants. The survey items were winnowed down through the content validity process, which helps reduce fatigue. Although the FPSEA Survey had good content validity, further psychometric studies are recommended. Future reliability and validity studies should have a larger sample size.

3.5 CONCLUSION

The development and initial evidence of the FPSEA's psychometric properties were reported in this article. Translational validation was used to finalize the FPSEA draft. The findings of this study indicate moderate repeatability of the survey. Previous researchers have yet to seek students with physical disabilities' perspective regarding their access to S&E laboratories. This self-report survey of past students with physical disabilities will be a beneficial contribution to the current empirical literature on identifying the barriers and facilitators to participating S&E laboratories. The FPSEA Survey will allow researchers to understand the perceived barriers and facilitators students with physical disabilities experience in S&E laboratories. To help ensure the survey items represent the intended use, future researchers should complete additional psychometric properties and a large pilot study. This survey, when implemented in the future, might provide more evidence of existing barriers and facilitators to S&E laboratories for students with physical disabilities, enabling SWD’ full participation in those fields.

4.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: INITIAL BARRIER FINDINGS

4.1 INTRODUCTION

Science, technology, engineering, and mathematics (STEM) jobs continue to remain unfilled by trained professionals. By 2024, STEM jobs are expected to grow by approximately nine percent, more than the projected non-STEM employment (6%) [81]. According to the U.S. Department of Commerce report in 2017, individuals in STEM help drive our nation's competitive edge [81]. One way to increase our nation's competitiveness and growth involves developing the untapped potential of people with disabilities (PwD) in engineering related fields [3]. Close to 70% of STEM workers have at least a bachelor's degree in STEM [81]. To date, PwD with at least a bachelor's degree constitutes 7.2% of the science and engineering (S&E) workforce [12].

A critical juncture to examine a fault in the pipeline to STEM employment is at colleges and universities, where students with disabilities (SwD) obtain the training that leads to STEM employment. There seems to be a blockage in the S&E pipeline that reduces the number of SwD who advance into STEM careers [12]. Examining the barriers SwD experience in their required laboratory classes may help to uncover issues in the S&E pipeline.

A recent literature review suggests three broad categories to group barriers and facilitators to laboratory participation: (1) the architectural built environment (BE) of the laboratory; (2) executing tasks (TE) in the laboratory space; (3) and learning environment (LE) of the physical S&E laboratory (e.g., interaction with student peers, and laboratory instructors) [59]. Most of the review's findings indicated that most of the barriers previously reported were anecdotal, thereby creating a need to empirically investigate the problem [59]. Moreover, key findings of the review indicated that future research should distinguish barriers to specific types of disabilities (e.g., physical disabilities) since previous research did not delineate the barriers that students with physical disabilities (SwD-P) encounter. To provide this empirical evidence, a national online survey was developed, and initial evidence of psychometric properties was reported (e.g., content validity and test-retest reliability) (*manuscript forthcoming*). The survey had good content validity and adequate test-retest reliability and indicated a need to run a larger pilot study to provide empirical evidence of existing barriers and facilitators experienced by SwD-P in an instructional science and engineering laboratory. As a reminder from chapter three, barriers are factors that hinders or prevents SwD-P from hands-on participation when using a laboratory. The purpose of this chapter is to report the initial findings from the survey administered to SwD-P to help identify barriers and facilitators to participation in a science or engineering laboratory for SwD-P.

4.2 METHODS

The survey (see Appendix A) was developed at the Human Engineering Research Laboratories (HERL) in Pittsburgh, PA. Initial psychometrics (e.g., content validity and test-retest reliability) were performed on the survey. The study was approved by the Institutional Review Board of the University of Pittsburgh. The survey was administered through Qualtrics online survey platform [69]. The online platform allowed participants to complete the survey using any computer or mobile device.

The survey had approximately 80 sub-items including demographic information. The first page of the survey included a description of the survey's intent and the consent form, asking the participant if they would like to consent by continuing the survey. As an incentive participates who completed the research study were entered into a drawing, 19 participants were randomly selected to win $25, using a random integer generator [68]. The inclusion criteria to take the survey aside from the consent were: 1) having to be 18 or older; 2) have a physical disability; 3) have been or are currently enrolled in a technical school or college; 4) and have taken or are currently taking a STEM-related course. There were no specific exclusion criteria.

Approximately 1,200 engineering-related companies, disability-affiliated organizations, colleges and universities in the United States were contacted with a request to distribute the survey to past and present students with physical disabilities. To reach the purposive sample, colleges and universities were randomly selected using a random integer generator on the Carnegie Classification system, a framework used to classify American universities [68], [82]. At least 20 schools were randomly selected from each of the high STEM-dominant universities, doctoral universities (i.e., R1, R2, and R3), master's universities (i.e., M1, M2, M3) and engineering-focused schools using the Carnegie Classification system. The doctoral universities (R1-R3) have high research activity and likely offer more opportunities for undergraduate science and engineering students. The Carnegie classification does not contain a special focus on science but does have a special focus on engineering programs; therefore, all seven schools were contacted from this list as well [82]. The disability resource center and dean of students of the schools were contacted to help distribute the survey. United States universities have also been contacted that are ranked among the top 100 worldwide universities granted U.S. utility patents in 2016, which were reported by the National Academy of Inventors (NAI) and the Intellectual Property Owners Association (IPO). Additional marketing channels for the survey included: university registries, special interest groups and networks: University of Pittsburgh's Clinical Science Technology

Institute Registry, Georgia Tech Center for Assistive Technology and Environmental Access (CATEA), American Society of Engineering Education (ASEE), Academic and Research Leadership (ARL), National Center for College Students with Disabilities (NCCSD), and the Disability Rights Expanding Accessible Markets Network (DREAM). Other forms of recruitment included web-based postings on online forums and social media (with permission) on Facebook, LinkedIn, and Twitter. Prospective participants were able to access the web link directly to the survey or contact the principal investigator directly.

4.2.1 Data Analysis

This study used mix methods that involved both descriptive statistics and qualitative content analysis. First, descriptive statistics are primarily used in survey research [57]. The descriptive analysis of survey results was conducted using IBM SPSS [75] and Microsoft Excel (2016). Descriptive statistics for each item were reported using frequency counts and percentages to help determine the prevalence of reported barriers in science and engineering laboratory settings. Second, qualitative content analysis was used for both open-ended responses in the survey, primarily using a deductive framework. The questions were: 1) Please list any assistive technology that helped you to complete laboratory tasks, and 2) Please list barriers in maneuvering or accessing the laboratory space. Using a deductive approach, mutually exclusive coding categories were developed from the International Classification of Functioning, Disability, and Health (ICF) taxonomy. An inductive approach was used to find patterns in the raw data to create new codes that did not fit into any of the existing ICF categories. As part of the qualitative content analysis process, the text was categorized, and their frequencies were reported [83]–[85].

4.3 RESULTS

4.3.1 Demographics of Sample

The results shown in Figure 3, reveal a total of 738 individuals consented to take the survey. Among these, 228 unique survey entries met the inclusion criteria. The data for a total of 107 participants were analyzed; others were excluded due to a combination of short time completion, incomplete surveys, and for not selecting a specific type of physical impairment. Table 15 displays the demographic profile of the survey participants. The average age of the participants was 28.7 years, with their ages ranging from 18 to 68. Over half the respondents (57.4%) were between 18 and 27 years old. The majority (65.3%) of the respondents were women. Similarly, the majority (69.3%) of respondents were Caucasian. Most (72.3%) respondents were in school at the time of completing the survey. Concerning physical abilities, most respondents reported having difficulty doing the following without assistance: sitting, kneeling, squatting, or bending (57.9%); climbing stairs (55.1%), or lifting or carrying objects in hands or arms (53.3%). Participants attended 67 unique schools across the United States, multiple respondents attended the following institutions: University of Wisconsin (7), University of Illinois (7), University of New Mexico (6), University of Alaska (5), University of Michigan (4), North Carolina State University (4) and the University of Pittsburgh (4). Sixty-four respondents reported the last four years to be their most inaccessible laboratory experience (2013-2017).

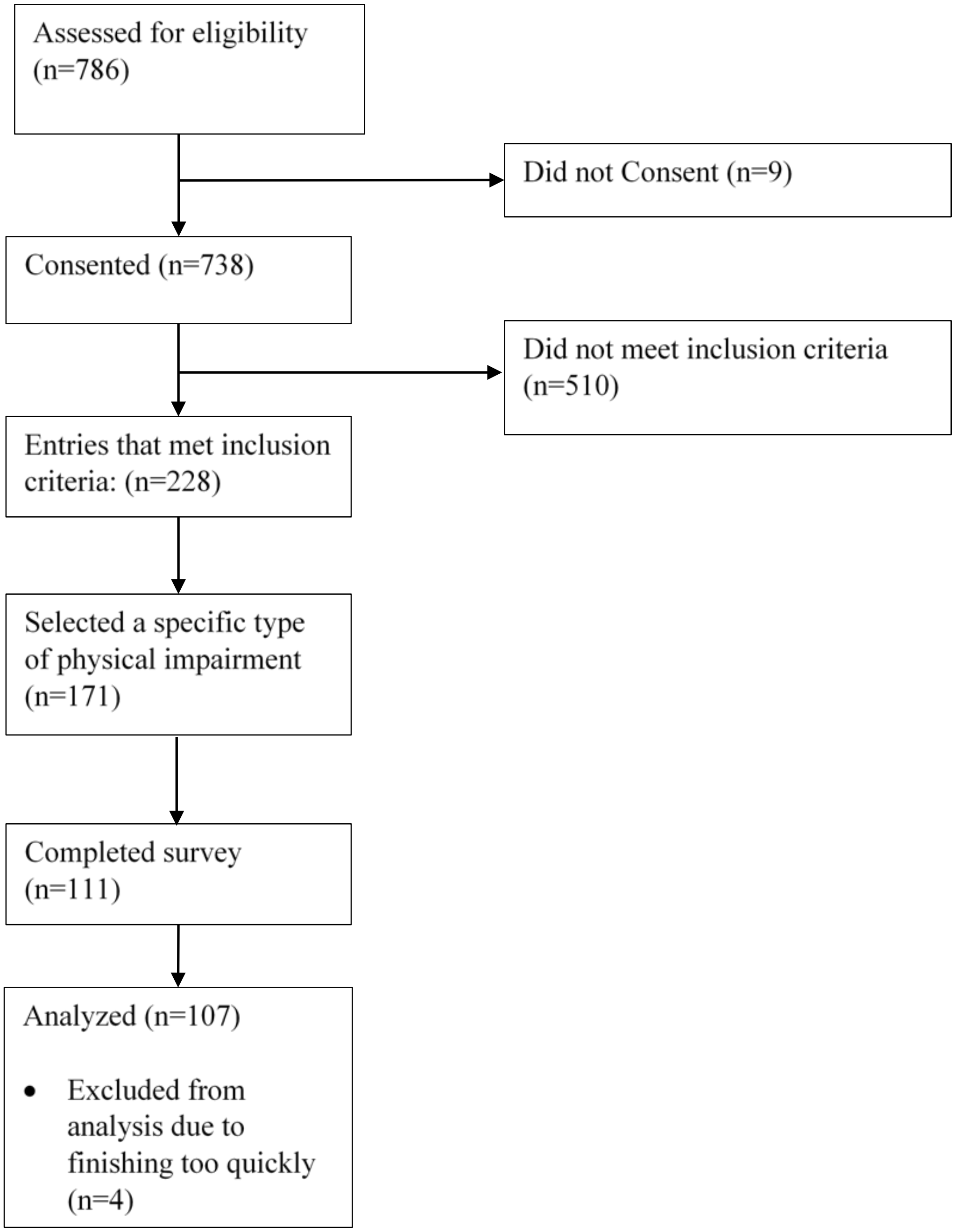

Figure 3. CONSORT diagram of participant inclusion

Table 15. Demographic Profile of Survey Respondents (n=228)

	n	%
Activities participants have severe difficulty doing without assistance (participants could choose more than one)		
Sitting, kneeling, squatting, or bending	62	57.9%
Climbing stairs	59	55.1%
Lifting or carrying objects in hands or arms (e.g. gallon of paint)	57	53.3%
Standing	48	44.9%
Walking	45	42.1%
Twisting, rotating, bending an object (e.g. using tools)	32	29.9%
Picking up or putting down objects	29	27.1%
Using fingers to handle small objects (e.g. coins)	29	27.1%
Crawling	28	26.2%
Reaching objects	20	18.7%
Grasping a tool or door knob	18	16.8%
Pulling door closed or pushing objects away	11	10.3%
The nature of participants' disability or diagnosis (participants could choose more than one)		
Paraplegia	7	6.9%
Tetraplegia/Quadraplegia	2	2.0
Absent limb/reduced limb function	8	7.9
Spina Bifida	5	5.0
Multiple Sclerosis (MS)	3	3.0

Table 15 (Continued)

	n	%
Cerebral Palsy (CP)	10	9.9
Muscular Dystrophy (MD)	2	2.0
Other	43	42.6
Gender		
Female	66	65.3
Male	32	31.7
Other	3	3.0
Missing Data	6	5.6
Ethnicity/Race		
White, non-Hispanic	70	69.3
Hispanic/Latino	9	8.9
Black/African-American	8	7.9
Multi-race (not Hispanic/Latino	5	5.0
Asian	3	3.0
Prefer not to answer	3	3.0
American Indian/Alaskan Native	2	2.0
Other	1	1.0
Native Hawaiian/Pacific Islander	0	0.0
Missing Data	6	5.6
Age of Participants (n=101)		
18-22 years	34	33.7
23-27 years	24	23.8
28-32 years	13	12.9
33-37 years	15	14.9
38-42 years	6	5.9
Over 42 years	9	8.9
Number of years with impairment (n=100)		

Table 15 (Continued)

	n	%
0-5 years	22	22
6-10 years	22	22
11-15 years	15	15
16-20 years	18	18
21-25 years	12	12
26-30 years	4	4
Over 30 years	7	7
Currently in school (e.g. college, technical school, etc.)		
Yes	73	72.3
No	28	27.7
Missing Data	6	5.6
Year of expected degree completion (of those in school)		
2017	6	8.3
2018	20	27.8
2019	22	30.6
2020	19	26.4
2021	4	5.6
2022	1	1.4
Degrees received (respondents may select more than one)		
High school diploma / GED	97	90.7
Associate's	16	15.0
Bachelor's	42	39.3
Master's	15	14.0
Doctorate (or equivalent)	9	8.4
Licenses	12	11.2
Type of school participant had the most experience using science or engineering laboratory		
Community College	13	12.9

Table 15 (Continued)

	n	**%**
2-year Technical College	5	5.0
4-year college or university	83	82.2
Missing data	6	5.9
Current employment status (may choose more than one)		
Student	71	66.4
Employee	31	29.0
Self-employed	6	5.6
Out of work and looking for work	12	11.2
Out of work but not currently looking for work	1	0.9
Military	1	0.9
Retired	3	2.8
Unable to work	8	7.5
Never worked	2	1.9

In the demographics portion of the survey 107 participants were asked to rate the accessibility of various laboratories used as shown in Table 16. Majority of respondents had experience using Biology, Chemistry, and Physics laboratories.

Table 16. Accessibility of science or engineering laboratories experienced. n (%)

	Missing Response	Very Accessible	Somewhat Accessible	N/A	Somewhat Inaccessible	Very inaccessible
Machine Shop, Plastics and Metals	7	5(5.0)	12 (12)	70 (70)	8 (8)	5 (5)
Chemistry	8	19 (19.2)	30 (30.3)	31 (31.3)	14 (14.1)	5 (5.1)
Biology	7	28 (28.0)	29 (29.0)	24 (24.0)	14 (14.0)	5 (5.0)
Physics	8	15 (15.2)	24 (24.2)	50 (50.5)	8 (8.1)	2 (2.0)
Electrical or Electronics	9	4 (4.1)	15 (15.3)	71 (72.4)	5 (5.1)	3 (3.1)
Mechanical Engineering	9	4 (4.1)	7 (7.1)	80 (81.6)	5 (5.1)	2 (2.0)
Chemical Engineering	9	2 (2.0)	5 (5.1)	87 (88.8)	3 (3.1)	1 (1.0)
Civil Engineering	9	3 (3.1)	2 (2.0)	87 (88.8)	5 (5.1)	1 (1.0)
Other	19	4 (4.5)	7 (8.0)	71 (80.7)	4 (4.5)	2 (2.3)

4.3.2 Barriers

The top two most inaccessible laboratory types reported were Chemistry (28.4%) and Biology (22.1%) as shown in Table 17.

Table 17. The most inaccessible laboratory

	n	%
Most inaccessible science or engineering laboratory		
Machine Shop, Plastics and Metals	12	12.6
Chemistry	27	28.4
Biology	21	22.1
Physics	9	9.5
Electrical or Electronics	3	3.2
Mechanical Engineering	4	4.2
Chemical Engineering	2	2.1
Civil Engineering	3	3.2
Other	14	14.7

4.3.2.1 Barriers - BE

Facilities

All 107 participants, responded to dichotomous items on barriers to reaching or entering the laboratory facilities. When examining access leading to science and engineering laboratories, architectural barriers continue to inhibit students from entering buildings and the laboratories, as shown in Figure 4. Using a dichotomous scale, a quarter of the survey respondents reported three major barriers to entering the facility. There were physical or informational (e.g., entrance signage) barriers to reaching the building's main entrance (24.3%). Survey respondents (23.4%) also indicated that that physical barriers remain at the building's entrance. Once inside the building, there are physical barriers to the laboratory entrance (25.2%).

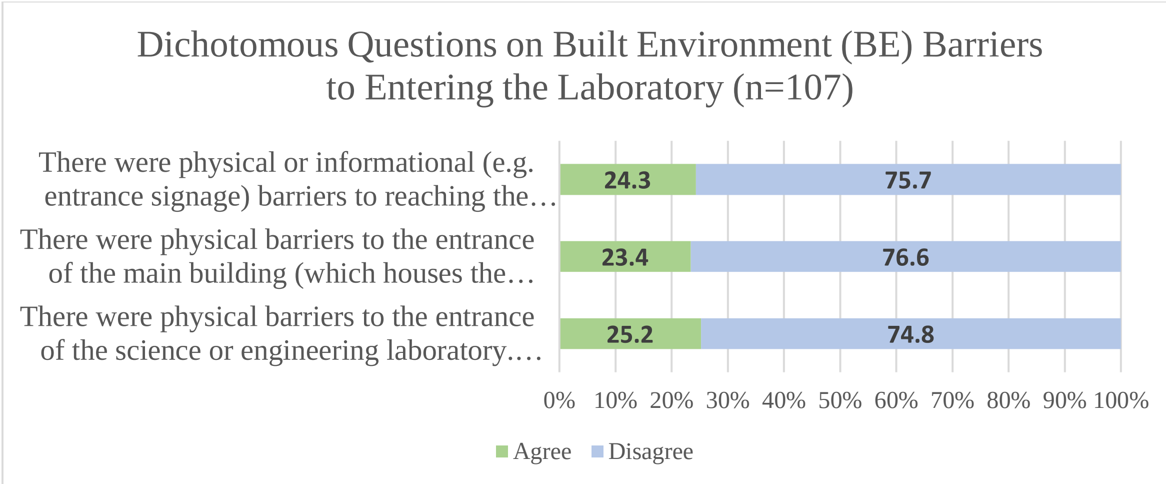

Figure 4. Dichotomous Questions on Built Environment (BE) Barriers to Entering the Laboratory

Due to branching logic in the survey, the remaining respondents (75%) who did not report entering the laboratory as a barrier, responded to follow-up questions on what made it easy to enter the laboratory. Of the 80 survey respondents who answered the Likert-scale questions on what made it "*easy when entering the laboratory space*" a large number of respondents agreed favorably on different factors. However, some respondents (22.6%) found that it was not easy to identify signs to an accessible entrance or did not report encountering any signs (25%). Similarly, participants found that doors were not easy to operate (20.1%) as shown in Figure 5. Of the 27 participants who answered the Likert-scale question on features that were barriers to entering the laboratory over half (51.8%) reported operating doors to be problematic and almost half (40.7%) reported that width of doors was the contributing factor as well.

The questionnaire also included an open-ended question on barriers to maneuvering or getting around the laboratory space (see Table 18). Based on the written feedback from 47 individuals, major barriers reported were aisles and pathways that were unclear or narrow (46.8%), cramped workspaces (31.9%), items being too close together (19%) or too high (19%). Written reports included all types of statements from: "*lab stools blocked pathways*," "*crowded room made* *egress difficult,"* "*doors were too heavy. Signs for accessibility are often blocked by construction,"* to being *"blocked by other student projects."*

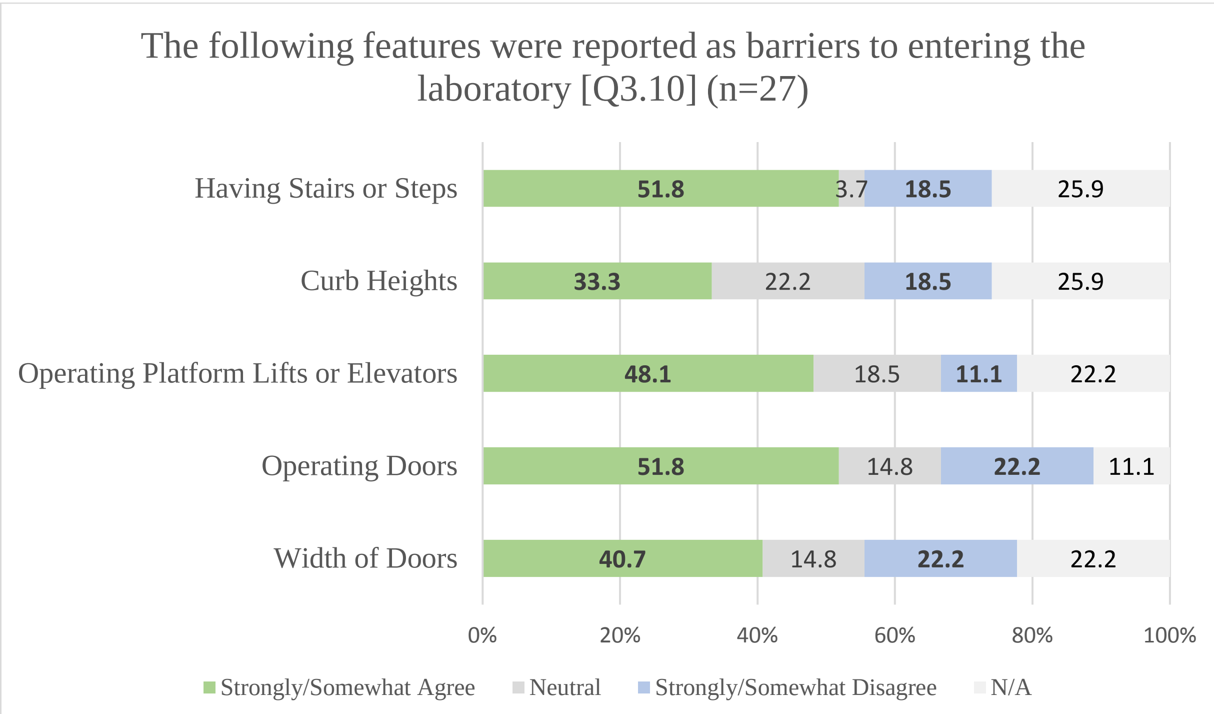

Figure 5. The following features were reported as barriers to entering the laboratory

Table 18. Barriers in maneuvering or getting around the laboratory space

Responses to "Please list barriers in maneuvering or getting around the lab space" (n=47)	
Statement related to gaining access to laboratory space	**Number of Mentions**
Unclear, narrow aisles or pathways • "lab stools blocked pathways" • "narrow aisles" • "The room wasn't so much a lab as it was a giant obstacle course"	22 (46.8%)
Cramped work spaces or crowded room • "small space between aisles and instruments" • "Crowded room made egress difficult"	15 (31.9%)

Table 18 (Continued)

Responses to “Please list barriers in maneuvering or getting around the lab space” (n=47)	
Statement related to gaining access to laboratory space	**Number of Mentions**
• “Equipment & supplies jam-packed on workbenches”	
Items too close together	9 (19%)
• "Tables too close together"	
• "Furniture close together"	
• “…enough space between aisles and instruments required”	
Inaccessible workstations/items too high	9 (19%)
• “counters too high”	
• “Tables too high and physically couldn't get my wheelchair underneath so I had to sit sideways when working with other student”	
• “Resources in high cabinets”	
Inaccessible lab features	5 (10.6%)
• “the sinks could not be reached”	
• "the counters were... not adjustable"	
• "opening drawers"	
Barrier getting to the workspace (E.g. steps)	4 (8.5%)
• “Small area between work spaces…steps in between work areas”	
• "Stairs getting into lab"	
• "there were no lever devices to possibly lift a wheelchair up to the working area."	
Equipment out of reach	2 (4%)
• “equipment out of reach for a person who uses a wheelchair”	
• "limited ladders to reach equipment in higher shelving"	
Other students' projects	2 (4%)
• “that were blocked by other student projects”	
Other Statements	
Furniture	8 (17%)
• “heavy chairs to move around”	
• "chairs meant for the counter work space that are too tall for the tables"	
• “The laboratory needs an up grade”	1
• “[The lab] required a lot of movement within”	1
• “Sitting on the ground to view lab problem data”	1
• "they often argued when I requested a stool that reached up to the table"	1
• "hard for me to stand the full lab period"	1

Table 18 (Continued)

Responses to "Please list barriers in maneuvering or getting around the lab space" (n=47)	
Statement related to gaining access to laboratory space	**Number of Mentions**
• "they often argued when I requested a stool that reached up to the table"	1
• "Measurements that require moving back and forth between a device and a desk"	1
• "no sitting options"	1
• "problem of opening doors "	1
• "cables"	1

4.3.2.2 Barriers -TE

When examining participation once inside the laboratory space, barriers were reported on executing tasks in the laboratory space (TE) regarding limits on participating during hands-on laboratory activities, laboratory setup, and operating equipment and the use of tools. Most respondents reported unfavorably to actively participating in their science or engineering laboratory, where less than half (49.5%) the respondents reported that the majority of their participation was not limited [Figure 6]. Many respondents noted much of their participation was limited to note-taking (37.4%), writing papers (24.3%), or writing software (8.4%). Of the 14% who selected 'other,' mentioned the majority of their participation was limited to "*observing while my partner completed tasks*," "*writing in Lab notebook*" or "*washing labware*."

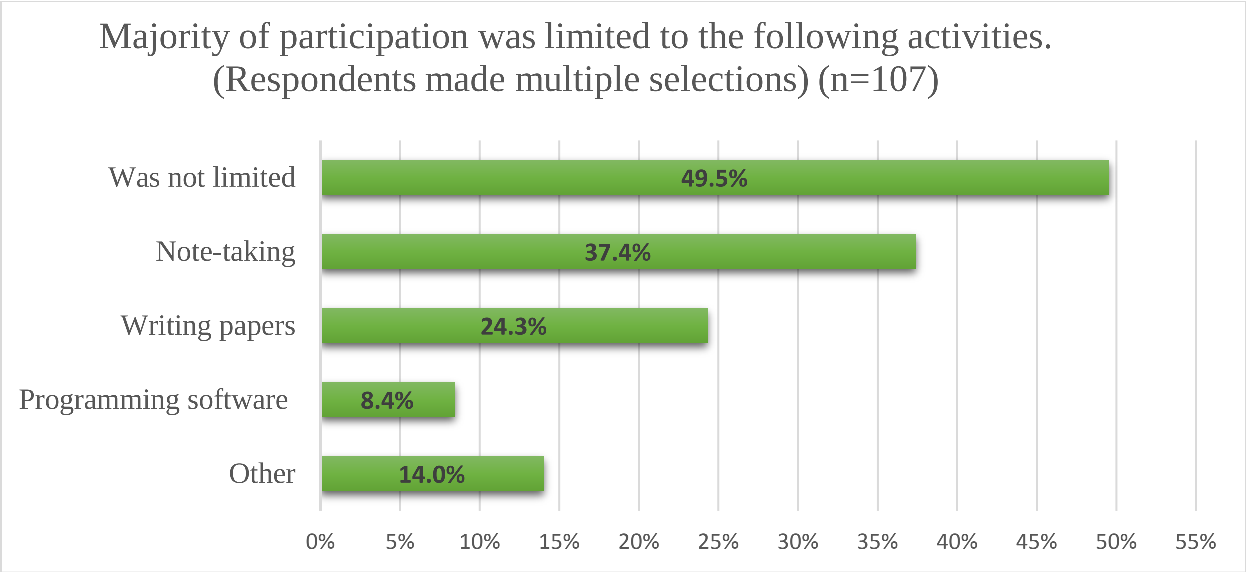

Figure 6. Majority of participation limited to the following activities.

Equipment and Tools

Laboratory Setup

Laboratory setup was reported as a barrier. When asked about laboratory setup on a 5-point Likert two-thirds of respondents (66.3%) of the participants indicated that "*there were physical barriers in setting up laboratory experiments or projects.*" The only insight that was revealed pertaining to laboratory setup was that there was not "*enough time allotted to independently setup laboratory experiments or projects,*" as reported by over a third of the respondents (34.6%) [Figure 7].

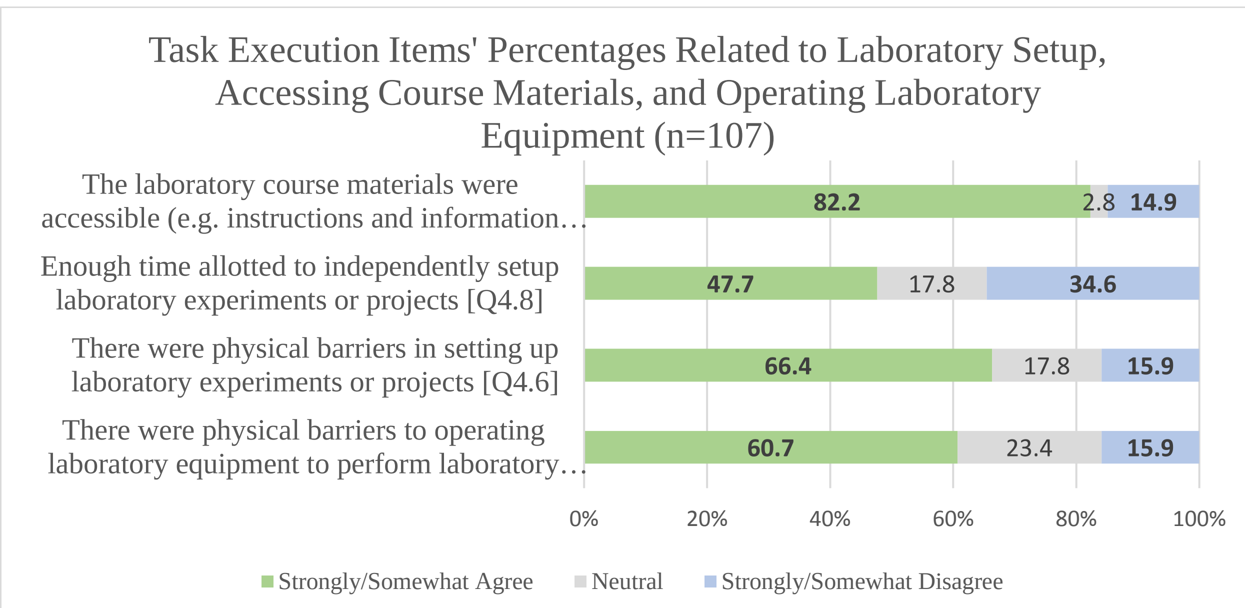

Figure 7. Percentages Related to Laboratory Setup, Accessing Course Materials, and Operating Laboratory Equipment

Operating Equipment and Using Tools

Critical barriers to fully participating in the laboratory includes operating laboratory equipment and using tools. Respondents were asked on a 5-point Likert scale about operating equipment, many (62.4%) respondents reported that there were "*physical barriers to operating laboratory equipment to perform tasks*" [Figure 7]. In examining this issue further, over one-third (38%) of the respondents reported that "*the laboratory equipment was not modified to complete laboratory tasks."* In addition to laboratory equipment not being modified, the use of laboratory tools were also found as a challenge. In a dichotomous item (Figure 8), almost half the respondents (46%) were not able to independently use all tools and other laboratory materials [Figure 8]. When asked about using tools and handling slippery material in a Likert-scale question, over a third of respondents reported that it was difficult to handle slippery material (37%) or gripping and clasping tools (44%), as shown in Figure 9.

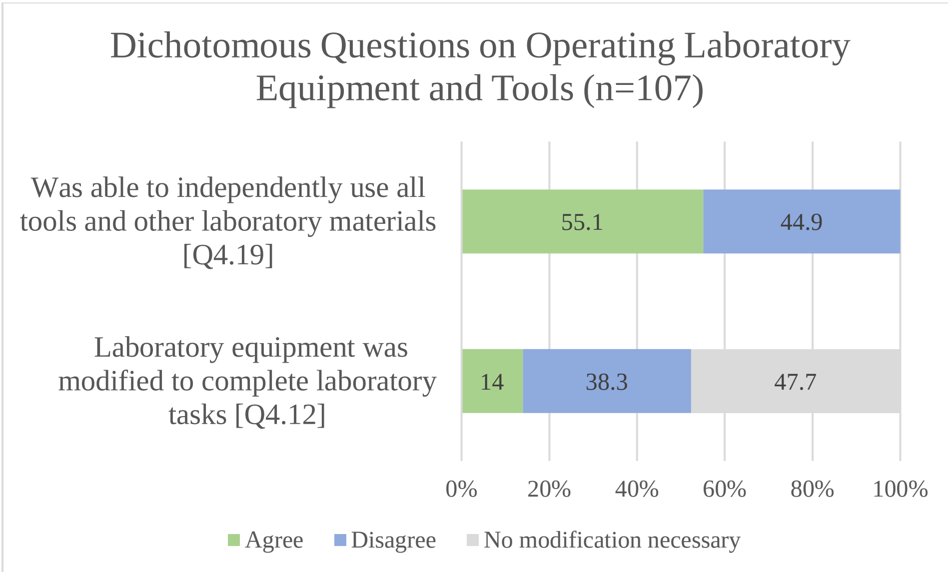

Figure 8. Dichotomous Questions on Operating Laboratory Equipment and Tools

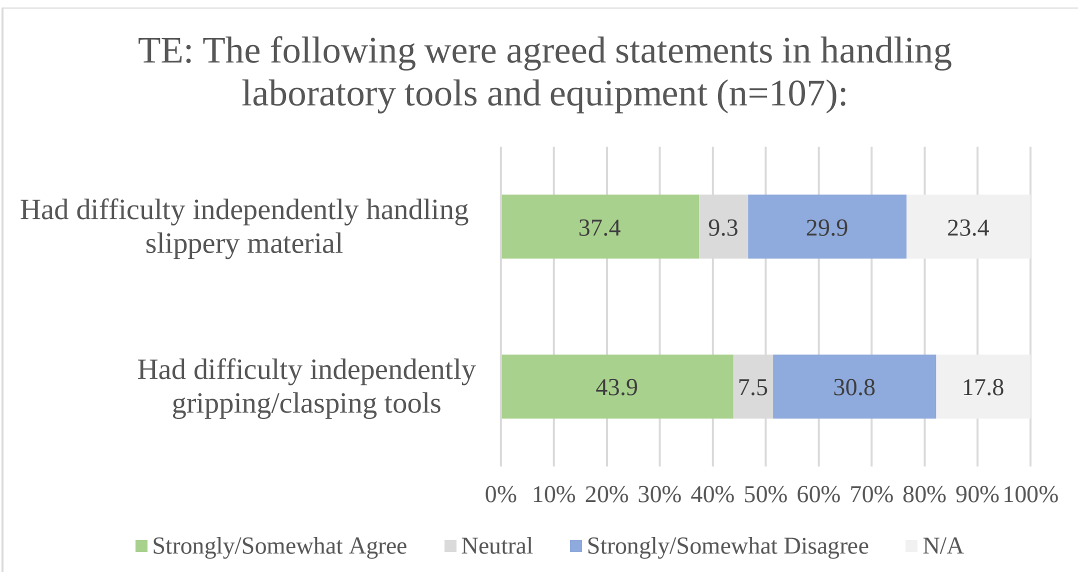

Figure 9. The following were agreed statements in handling laboratory tools and equipment

On a five-point Likert scale, 107 respondents were asked if they found several statements to be true regarding the use of laboratory equipment and reported that challenges continue to exist within the laboratory. Only one person skipped these set of questions. Almost half (40.6%) the respondents believed that the controls were not reachable from a seated position. Approximately a quarter (24.6%) of respondents did not find the control knobs of laboratory easy to operate or did not have control knobs to operate laboratory equipment (23.6%). Moreover, most (61.3%) respondents found that assistive technology did not apply (i.e., did not exist) for them to operate laboratory equipment, as shown in Figure 10.

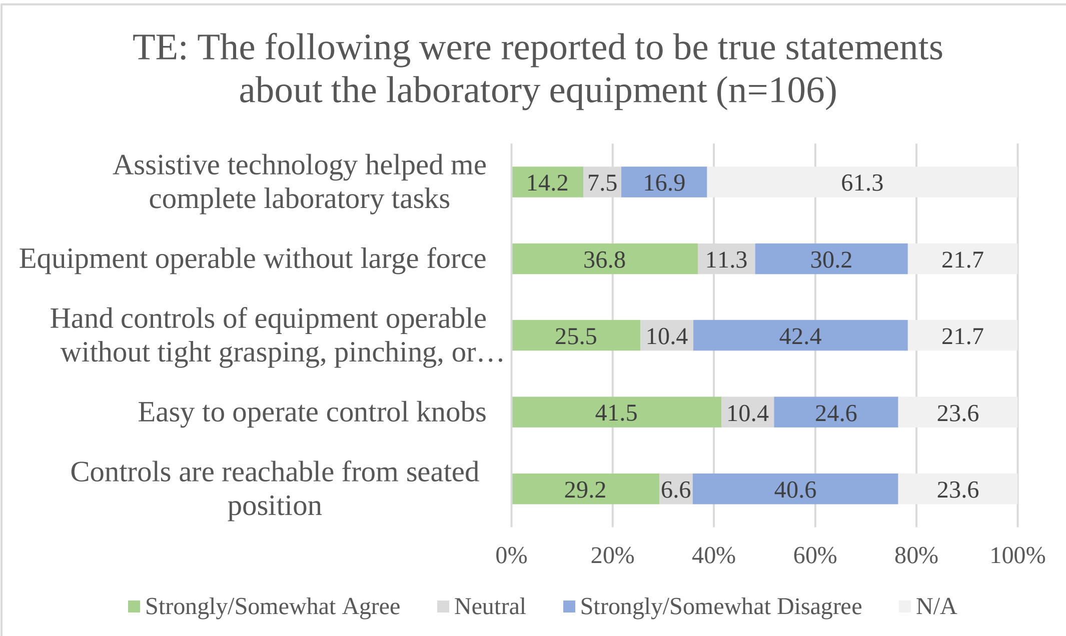

Figure 10. The following were reported to be true statements about the laboratory equipment

4.3.2.3 Barriers - Learning Environment (LE)

Participants rated statements regarding instructors or laboratory assistants while working in the laboratory space. As noted above, many participants reported that their laboratory experiences were limited. Participants indicated that some (27.1%) instructors believe that students with disabilities should conduct a scientific investigation as an observer [Figure 12].

Nevertheless, two-thirds (66.4%) of respondents indicated that instructors were willing to accommodate a student's specific needs, while almost one-fifth (16.8%) of respondents were not willing to do so [Figure 12]. Almost a third (30.8%) of participants also reported that instructors or laboratory assistants lacked the knowledge about how to provide accommodations to students with disabilities [Figure 11].

More participants felt that practices were not in place to support accommodations than did those who felt that the practices were established. Only 35.5% of participants felt that practices were in place to provide accommodations, whereas 46.8% felt that these practices were not in place [Figure 12].

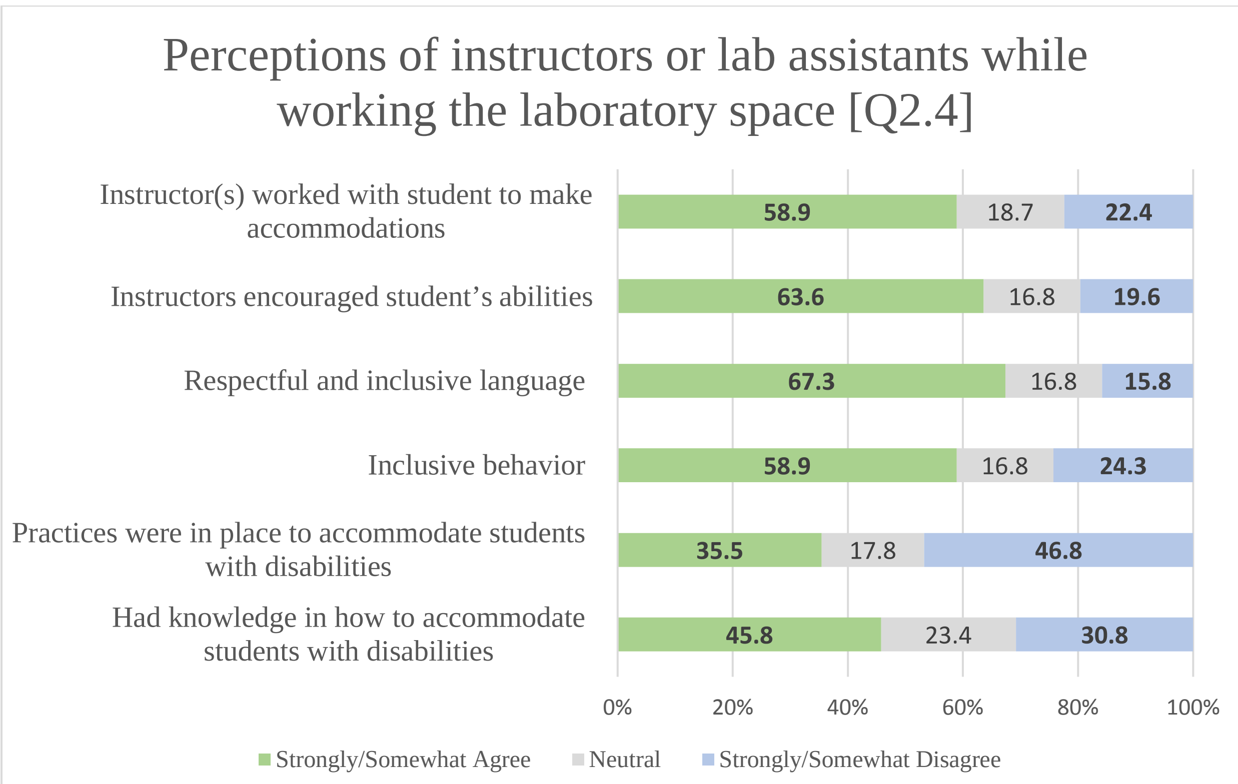

Figure 11. Statements regarding instructors or lab assistants while working the laboratory space

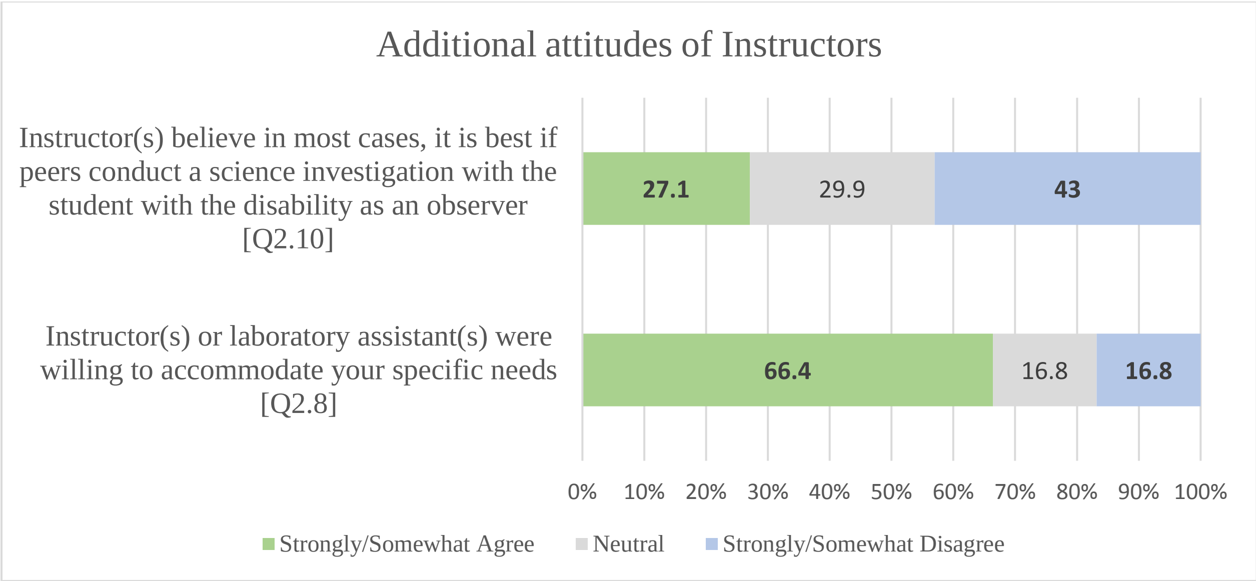

Figure 12. Additional Perceptions of Laboratory Assistants and Instructors

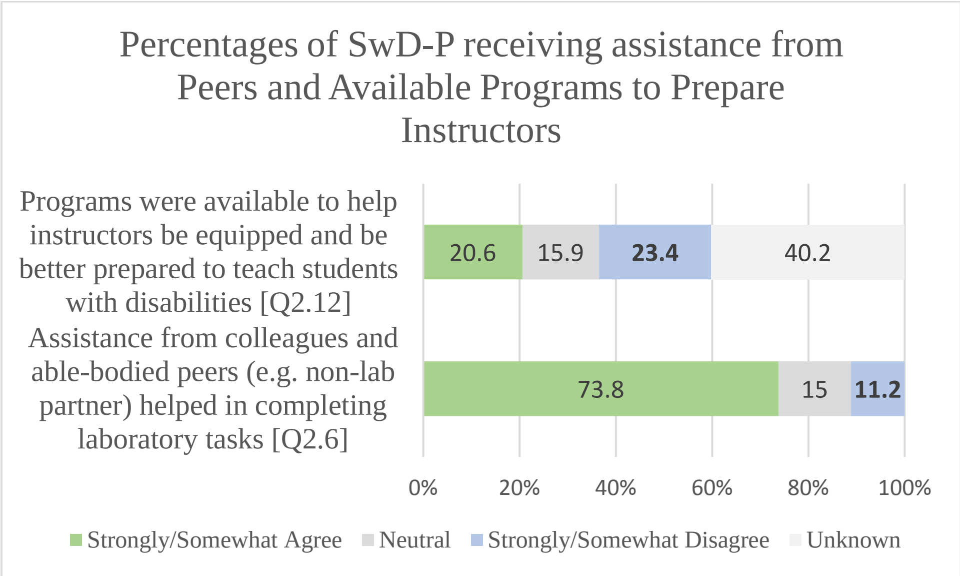

Figure 13. Percentages of SwD-P receiving assistance from Peers and Available Programs to Prepare Instructors

4.4 DISCUSSION

This survey of over 100 participants identified some of the current challenges and solutions to participating in an S&E laboratory from the perspective of SwD-P. Majority of the respondents were college-aged Caucasian women with mobility impairments or who had experienced difficulty lifting and carrying objects, who attended institutions from various parts of the U.S., within the past four years. The results from the survey help to reduce the gap in research by offering evidence on barriers and facilitators to full participation in instructional S&E laboratories for SwD-P. The empirical data from the survey contributes to the S&E accessibility literature on barriers and facilitators with perceived insight directly from SwD-Ps within the BE, TE and LE domains that can impact SwD-Ps future success.

4.4.1 Contributions to S&E Accessibility Literature on Barriers

The barriers found are categorized into the subsections within the BE, LE and TE domains as the facility, equipment, tooling, materials and learning within the laboratory environment.

4.4.1.1 Barriers: Built Environment Facility

Duerstock et al. [86] also identified inaccessibility to laboratories as a major barrier, which may be due to the obstructive pathways getting to the machines. Helping administration and instructors be more aware of barriers associated with entering the facility and reaching areas within the laboratory (e.g., laboratory workstations) continue to be a hindrance for SwD-P, may help increase participation. This research confirms similar findings concerning reaching and gaining access to buildings where the S&E laboratory is located (25%). While a large (75%) number of students reported that entering laboratory spaces was not an issue, a quarter of the respondents still found this issue to be a problem which hinders SwD-P from accessing the laboratory space to fully participate in the laboratory. Of those who did not find entering the lab space an issue, that too had other barriers to report such as: identifying signs to the accessible entrance (23%, n=80), using and operating doors (20%, n=80) made it a hindrance for entering the laboratory space. For example, one respondent noted "*doors were too heavy. Signs for accessibility are often blocked by construction.*" Once inside the laboratory workspace students have to deal with other complications that hinder their movement within the laboratory space to become active participants such as cramped work areas, obstructive pathways, and high table tops which empirically confirms information found in the literature [37], [48].

4.4.1.2 Barriers: Task Execution -- Equipment and Tools

Although close to half of the respondents reported that full participation of the laboratory of SwD-P was not limited, participation was still limited to passive roles such as note-taking (37%), rated the highest and to programming (8%), rated among the lowest. Note-taking is a critical part of the laboratory experience, which makes sense why students were more often relegated to notetaking activities than programming, since programming is not as widely used across different laboratory settings (e.g., wet laboratories). Four participants commented that their participation was "*limited to observing.*" Duerstock and colleagues [14] anectodally mentioned these tasks suggested that in some cases SwD-P were often mere observers. This activity has, now been empirically confirmed through the survey results. Assigning SwD-P to be passive observers was mentioned in Norman and colleagues' [18] article, who found that 15% of responding college science instructors believed that SwD-P could not be an active participant in all science laboratory exercises [17]. Burgstahler et al. [87] share some insight on this behavior by mentioning inequality of bias against SwD in postsecondary settings due to faculty having limited knowledge in appropriate accommodations for SwD in the classroom. This limited knowledge and lack of practices for making accommodations was also confirmed by the participants in this study and is covered more in the LE domain below. These hindrances may play a role in the skills students obtain during their laboratory experience, which may negatively impact their experiences moving into S&E career fields.

Once inside the laboratory areas everything from laboratory setup to using equipment and tools in the laboratory environment continues to be a hindrance for SwD-P. A hindrance to the laboratory experiment setup may be due to not enough time allotted for setup as reported by participants (34%). Heidari [48] shared in the past that not having enough time for laboratory setup promotes a barrier, and based on our survey results this continues to be an issue.

More specifically, SwD-P may not obtain appropriate laboratory experience due to reaching and dexterity issues with laboratory equipment and tools. Approximately, three times (38%) as many respondents shared that equipment was not modified to complete laboratory tasks, compared to those (14%) who did. One reason may be due to, almost half (45%) of the respondents were not able to independently use tools and laboratory materials, which may due reaching issues.

Findings from Burgstahler and Nouse [88], reveals that laboratory equipment is hard to reach. Another reason may be related to having upper extremity or fine dexterity issues leading to difficulty with gripping and grasping tools as reported by almost half the participants (44%) and echoed in other studies [26]. These findings solidify the literature with empirical data that laboratory equipment are inaccessible [34], [40], [44] which supports information in the literature on laboratories lacking adequate accommodation [38]. Helping administration and instructors build awareness around laboratory issues may help to promote full participation in the laboratory space. Instructors can work with students to ensure students are not left to passive roles but become more engaged in laboratory activity based on the student's abilities.

4.4.1.3 Barriers: Learning in the Laboratory Environment

As mentioned earlier students were limited to either passive roles, or simply observing, which may be related to some instructors' attitudes or lack of preparation as a result hindering SwD-P's participation. Multiple participants report that these negative views and lack of accessibility and accommodations have led to changing majors or not completing degrees. Negative views continue to play a role in SwD-P success into completing undergraduate degrees, as noted by a participant "*A large part of the reason why I discontinued biology as a major was because one of my instructors told me three weeks into a course that accommodating me would be too expensive and unfair to other students*." Similarly, Norman and colleagues [18] found that 7.0% college science instructors agreed that SwD should serve as observers instead of fully participating in laboratory activities.

In the same study, a low percentage (6.5%) of college science instructors felt that they were adequately prepared to teach SwD-P [18]. An additional layer of challenge is presented when administration and instructors are not familiar with how to support SwD-P. Many participants reported that practices were not in place to accommodate students with disabilities (SwD), this may be due to instructors who may not know how to accommodate SwD. As noted from one of the participants "*some teachers are not sure what to do sometimes*." As Alston and Hampton [89] pointed out instructors may not understand the needs and capabilities of SwD or even make additional efforts to accommodate SwD [89]. Only a smaller percentage of university science instructors (19.6%) felt prepared to design, select and modify tasks for teaching science to SwD [18]. The results suggest improvements in instructor's attitudes to make more of an effort to accommodate SwD-P. One participant in particular reference a negative experience with an administrator from the Disability Resource Services (DRS) on his/her campus. The participant commented on his/her experience with the DRC when s/he wrote:

> *Disability services was condisending [sic] and recommeded that I should consider not completeing my degree as the result of my health developments. I'm now 7/8 of the way done with my degree and two minors as the result of my hard work and a number of friends that assist me with tasks that I would otherwise be unable to complete. There have also been a few lab TA's that have helped me through some of my more difficult labs; however, there was not help given at the Chemistry lab and I (along with several other disabled students) was strongly discriminated against by our Organic Chemistry Professor. This is why I've been unable to complete this course (required for my degree).*

In general administrators in the DRS on campus are hired to provide a myriad of auxiliary aids that empower SwD to gain independence, achieve academic success and develop career goals to demonstrate their full potential. Nonetheless, to receive these services SwD are encouraged, but not required, to register with the DRS and provide appropriate diagnostic documentation to receive support services to which they might be entitled. While some instructors might rely on guidance for accommodations based on recommendations from administrators in the DRS, it is important to note that not all SwD-P register with the DRS to request accommodations and not all administrators are positive influencers on students' aspirational goals. Moreover, it is possible that the administrators in the DRS might act as barriers gatekeepers to SwD who want to pursue careers in S & E.

4.4.2 Limitations

While most people today have or are familiar with using computers and mobile devices (e.g., smartphones), this study is primarily suited to meet the needs of those who have electronic access to a mobile device with internet capabilities. Those who do not have internet capabilities would have to go through additional steps to complete the survey. Moreover, when filling out the survey, the study requires the ability to enter responses and select ratings on a scale for most items. If the respondent does not have the physical ability to do so, it is up to the user to ensure the appropriate assistive technology or software is installed on their machine (e.g., Dragon) to respond to the survey questions. Nevertheless, the survey is section 508-compliant, and the online platform makes it user-friendly and adaptable to meet the needs of various disabilities. The survey was constructed in English and was not validated for other cultures or languages.

4.4.2.1 Sample

Various institutions across the nation were contacted. However, every past and present SwD may not receive the announcement sent to their institutions. Disability-related organizations and Fortune 500 companies were contacted to disseminate the survey as well. The participants may be distracted and become interrupted while completing the survey. As part of this cross-sectional study, researchers are not able to follow-up with phone calls to ask clarifying questions. However, this survey does include comment boxes that allow the respondents to explain to elaborate on their responses.

4.5 CONCLUSION

The findings of this study highlight perceived barriers SwD-P encounter in instructional S&E laboratories and can help drive research and development work. Moreover, the results provides some insight of understanding the lack of access to full participation from the architectural environment to interaction with others within the laboratory environment. In addition, gaining access to the facility continues to be a barrier despite, the enactment of the ADA. These findings suggest that while ADA has lessened some barriers for SwD-P, more research is needed in the area. However, more information is needed to determine for whom and where these barriers exist.

While barriers in gaining entry to buildings or the laboratory itself is still a concern for this population, so is their role once in the laboratory space. On average, individuals reported they felt that they were assigned roles, while meaningful, are passive roles. Full participation for SwD-P in the laboratory space is still limited to passive roles at times. SwD-P find it a challenge to set up the laboratory and use the equipment. When it comes to interaction with instructors and peers, most found well-meaning teachers who were willing to help, but were not equip with the knowledge of how to help. Students found that some instructors and administrators still have negative viewpoints and that practices are still not in place to accommodate SwD-P. On The contrary, many found their peers and group members to be helpful. Barriers that remain unaddressed will continue to preclude SwD from participating in laboratory spaces. This research warrants further study of barriers in the postsecondary instructional science or engineering laboratory setting.

5.0 PARTICIPATION IN SCIENCE AND ENGINEERING LABORATORIES FOR STUDENTS WITH PHYSICAL DISABILITIES: INITIAL FACILITATOR FINDINGS

5.1 INTRODUCTION

The previous chapter addressed the students' perceived barriers in the postsecondary instructional science or engineering laboratory setting. From the SwD's perspective, the barriers included instructors' misperceptions of challenges along with navigation of the physical laboratory space. In contrast to the barriers presented in previous chapter, this chapter presents the findings on the perceived facilitators in the postsecondary instructional science and engineering laboratory setting.

As a reminder from chapter three facilitators are factors that enable SwD-P to have hands-on participation when using a laboratory. Facilitators include accommodations or strategies such as moving an emergency eyewash basin further apart from the supply line for easier access when using a wheelchair. Another type of facilitator includes having an assistive technology to support the use of reaching laboratory equipment or control buttons. Facilitators can be physical (e.g., assistive technology) and non-physical (e.g., hired laboratory assistants).

This chapter is organized in the same manner as the previous chapter. Both chapters share the same methodology, descriptive sample, and literature review. To that end, a discussion of the methodology, the descriptive sample, and the limitations will not be repeated in this chapter. However, an overview information from existing literature is restated for easier readability and convenience.

The literature review in chapter two suggests three broad categories to group barriers and facilitators to laboratory participation: (1) the architectural built environment (BE) of the laboratory; (2) executing tasks (TE) in the laboratory space; (3) and learning environment (LE) of the physical S&E laboratory (e.g., interaction with student peers, and laboratory instructors) [59]. Most of the review's findings indicated that most of the facilitators previously reported were anecdotal, which created a need to empirically investigate the problem [59]. Moreover, key findings of the review indicated that future research should distinguish facilitators to specific types of disabilities (e.g., physical disabilities) since previous research did not delineate the facilitators that students with physical disabilities (SwD-P) encounter. To provide this empirical evidence, a national online survey was developed, and initial evidence of psychometric properties was reported (e.g., content validity and test-retest reliability) (*manuscript forthcoming.*). The survey had good content validity and adequate test-retest reliability and indicated a need to run a larger pilot study to provide empirical evidence of existing barriers and facilitators experienced by SwD-P in an instructional science and engineering laboratory. The purpose of this chapter is to report the initial findings of the survey administered to help identify facilitators to participation in a science or engineering laboratory for students with physical disabilities.

5.2 RESULTS

5.2.1 Facilitators

5.2.1.1 Facilitators - BE

Physical Accommodations

When examining physical accommodations to entering science and engineering laboratories, architectural supports such as elevators and ramps were deemed helpful as shown in Figure 14. Of the 80 respondents who did not find entering the laboratory space an issue over two-thirds (67.1%) of respondents reported that operating elevators were easy, whereas 8.8% of respondents felt that operating elevators were not easy. Many (42.5%) respondents also reported that using curb cuts or ramps were easy to use.

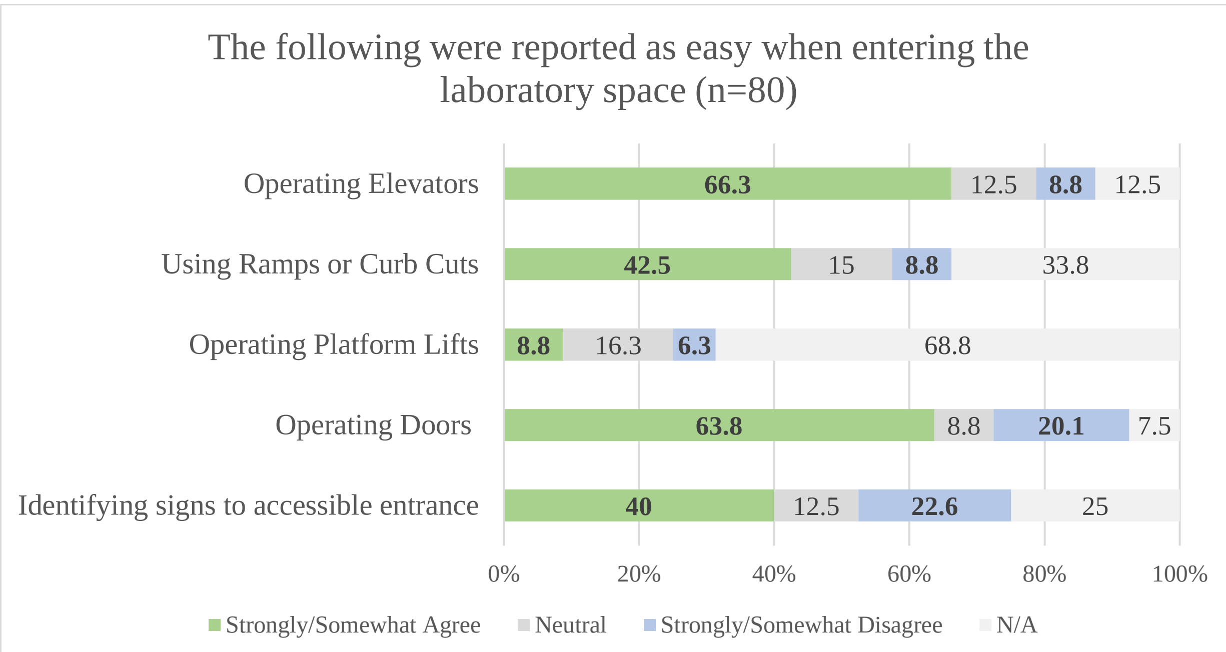

Figure 14. The following were reported as easy when entering the laboratory space

Workspace Modifications and Strategies

Inside the laboratory space, respondents reported, in a Likert-scale, the following factors made it easy to use the laboratory space: clear aisles (50.5%) and power strips placed within reach (38.4%). Even though some respondents (15%) found that height adjustable tables were easy to use, more respondents (33.6%) reported they were non-existent. Still, even more (44.9%), respondents found them not easy to use Figure 15.

Nonetheless, workspace modifications were helpful participation in the laboratory space. As in Figure 15, when asked about accommodations to using the laboratory space, respondents reported that accessible drawers and countertops (46.7%), accessible sinks and faucets (35.5%), made it easy to use the laboratory space. Also echoed in Figure 16, of the 55 respondents that reported on accommodations, using a dichotomous scale, indicated that accessible countertops (63.6%), sinks and faucets (63.6%) were helpful laboratory features. In addition to countertops and sinks, respondents reported accessible workbenches (67.3%), accessible cabinets (54.5%) were helpful laboratory features.

In Figure 17 regarding safety procedures being addressed, the respondents (58.9%) reported that accessible emergency exits were addressed. Over half (56.1%) of the respondents reported that accessible emergency eyewash basin were addressed and out of 106 individuals who responded over half (49.1%) believe that shower pulls were addressed.

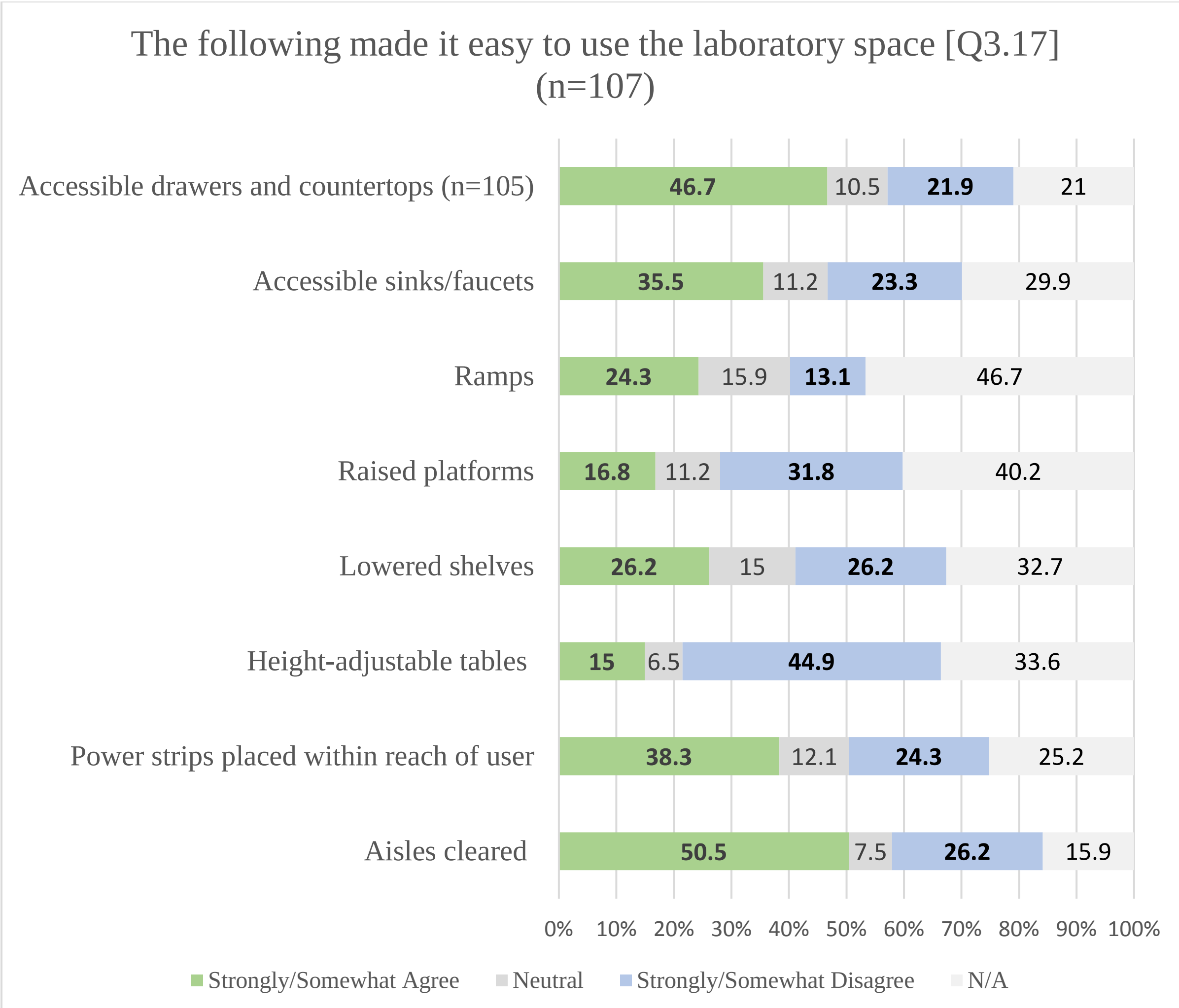

Figure 15. The following made it easy to use the laboratory space

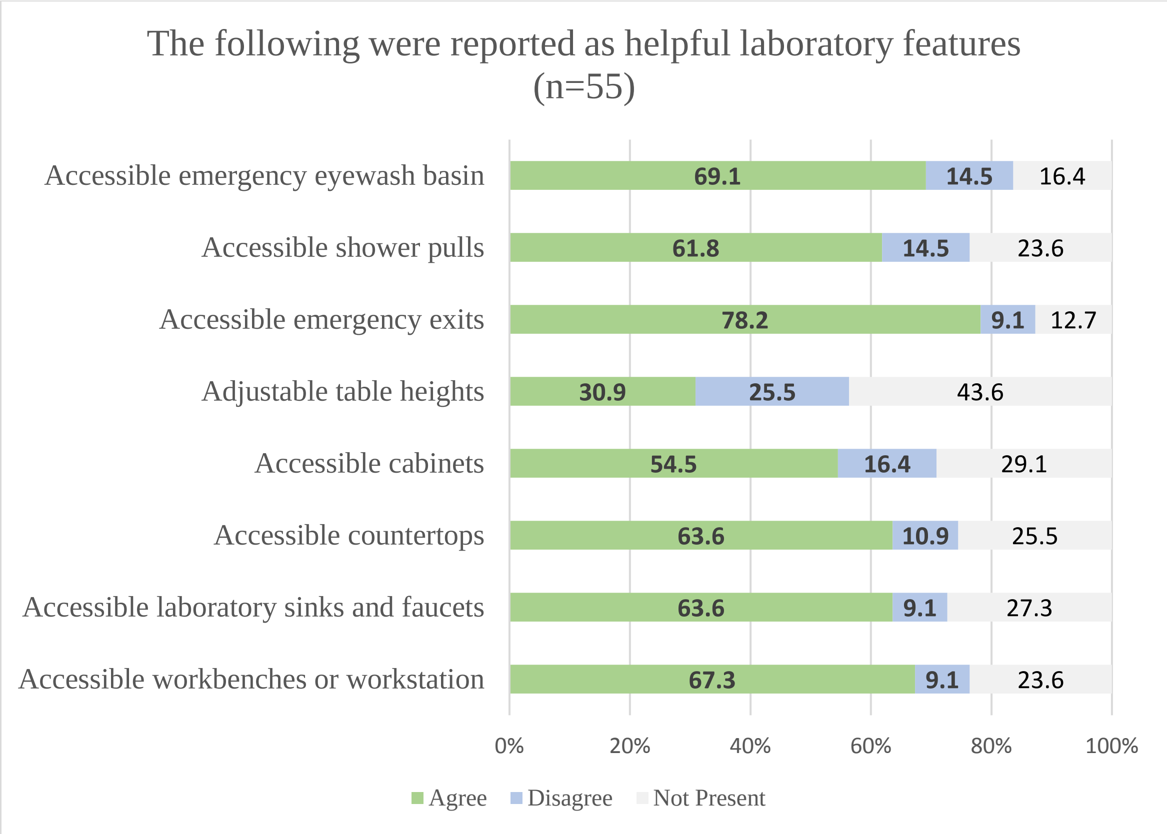

Figure 16. The following were reported as helpful laboratory features

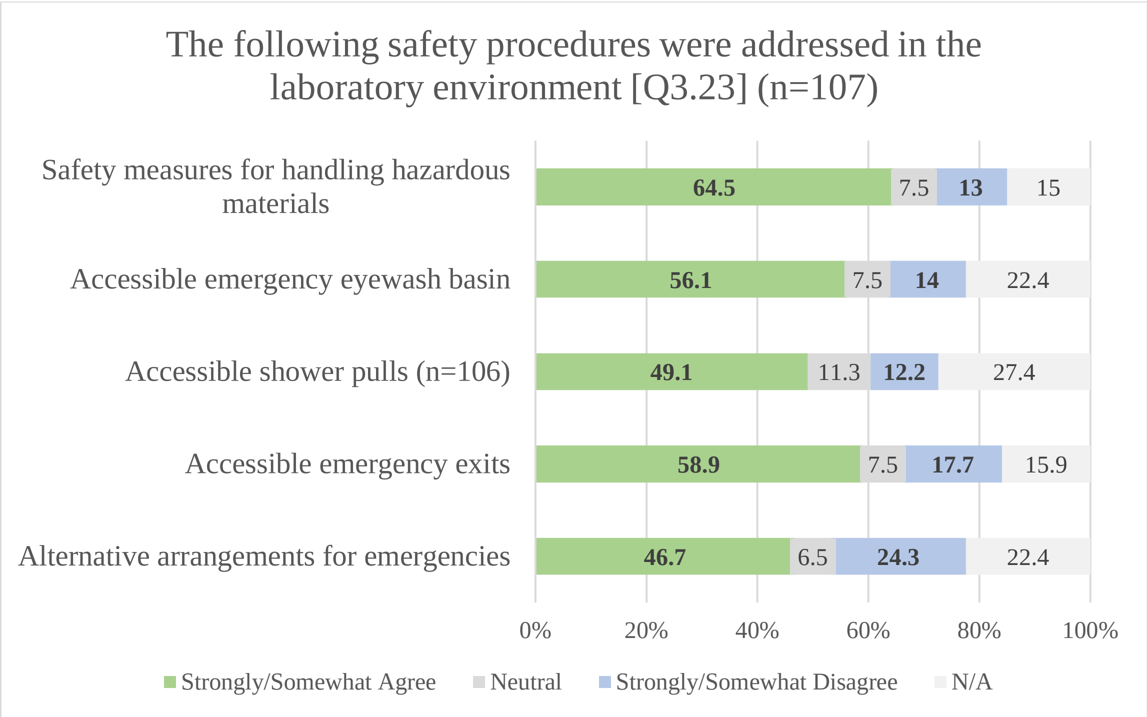

Figure 17 The following safety procedures were addressed in the laboratory environment

5.2.1.2 Facilitators - TE

Equipment Redesign and Strategies

When examining strategies for participation inside the laboratory, access to course material was the only dominating support as shown in Figure 7 in chapter four. Majority (82%) of respondents reported that course material (e.g., instructions and information) were accessible to allowing them to participate in laboratory activities.

Additionally, equipment redesign (e.g., accessible microscopes) and other facilitators were reported. The questionnaire also included an open-ended question where participants could identify any assistive technology that helped them complete laboratory tasks. Written feedback from 37 individuals, most of the facilitators identified were related to alternative products for education (32.4%), such as having a dictation software, laptop or digital recorder. Adapted technologies were also reported (5.4%) such as modified microscopes; the remaining assistive technologies are located in Table 19.

Table 19. List of AT that to complete laboratory tasks

Responses to "List any AT that helped you to complete lab tasks" (Q4.18) (n=37)	
Statements	Number of Responses
Alternative products OR Non-adapted technology/equipment for education • "Read and Write Gold" • "digital recorder" • "laptop"	12 (32.4%)
Adapted technology • "Modified microscopes"	2 (5.4%)
AT products for transportation (e.g. wc) • "seat elevator on wheelchair" • "Crutches"	2
Gaining access to facility/building • "Remote log in so I could work at home" • "Elevators"	2
Positions of authority • "My lab instructor pushed my wheelchair…" • "the graduate assistant preformed all tasks that I was uncomfortable with for me"	2
Other statements	
• "Note taker"	1
• "…I had an amazing friend as a lab partner lol"	1
• "U.S. Navy bootcamp and operations specialis "a' school in dam neck, Virginia in 1996" [sic]	1
• "Seats"	1

When asked about specific supports in operating the laboratory equipment majority of respondents found the feature to be non-existent or did not apply. However, more participants found features to be helpful than not as shown in Figure 18.

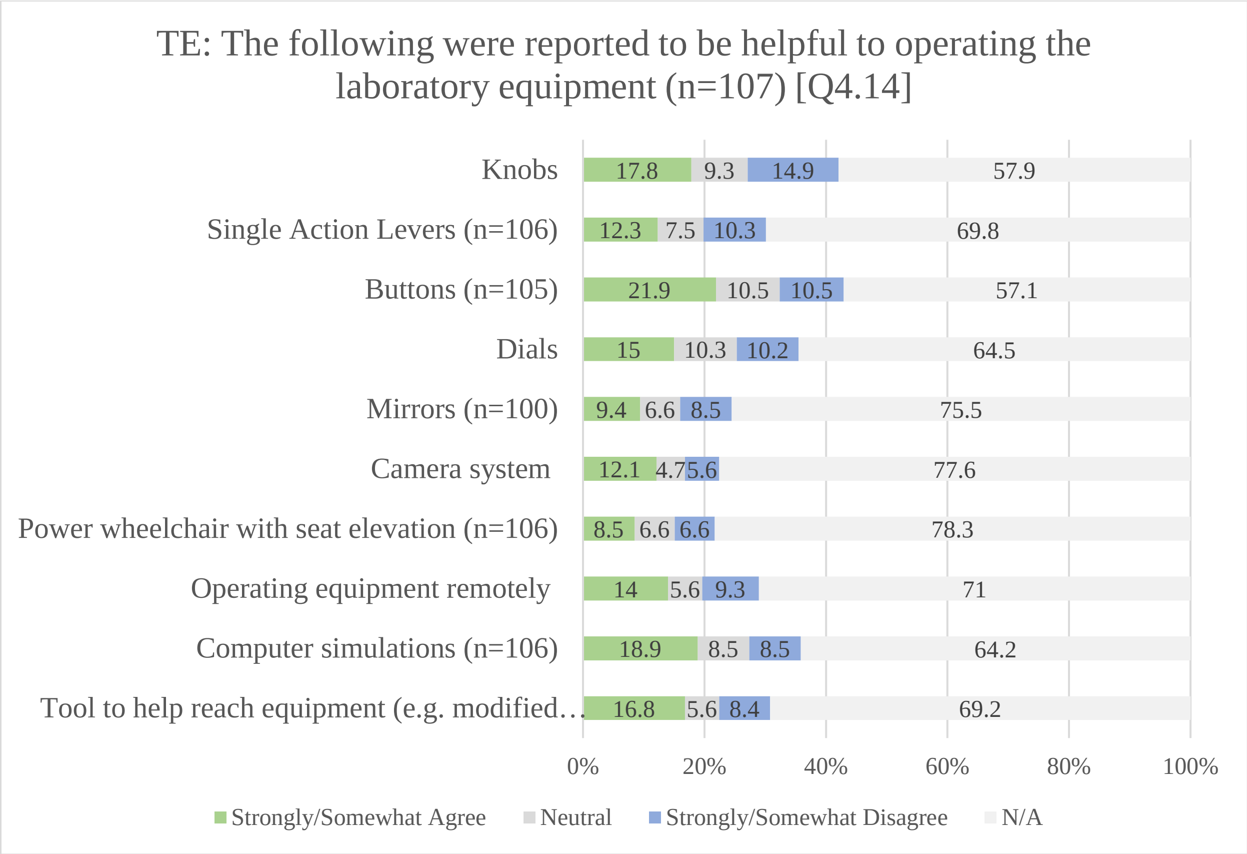

Figure 18. The following were reported to be helpful to operating the laboratory equipment

5.2.1.3 Facilitators - LE

Attitudes and Strategies

Even though there were negative perceptions of instructors, most respondents had a positive perception of their laboratory instructors as shown if Figure 11. At least two-thirds of respondents felt that their instructors used respectful and inclusive language or encouraged students' abilities. The percentage (63.6%), of students who felt this way was three times as many participants who felt otherwise (19.6%). Although students had a positive perception of their instructors, respondents found much more support from peers. As shown in Figure 13 above in chapter four, the majority of the respondents (73.8%) reported that assistance from colleagues and able-bodied peers were helpful in completing laboratory tasks. Similarly, in Figure 19, most respondents (78.5%) indicated group members to be most helpful in fully participating in the laboratory.

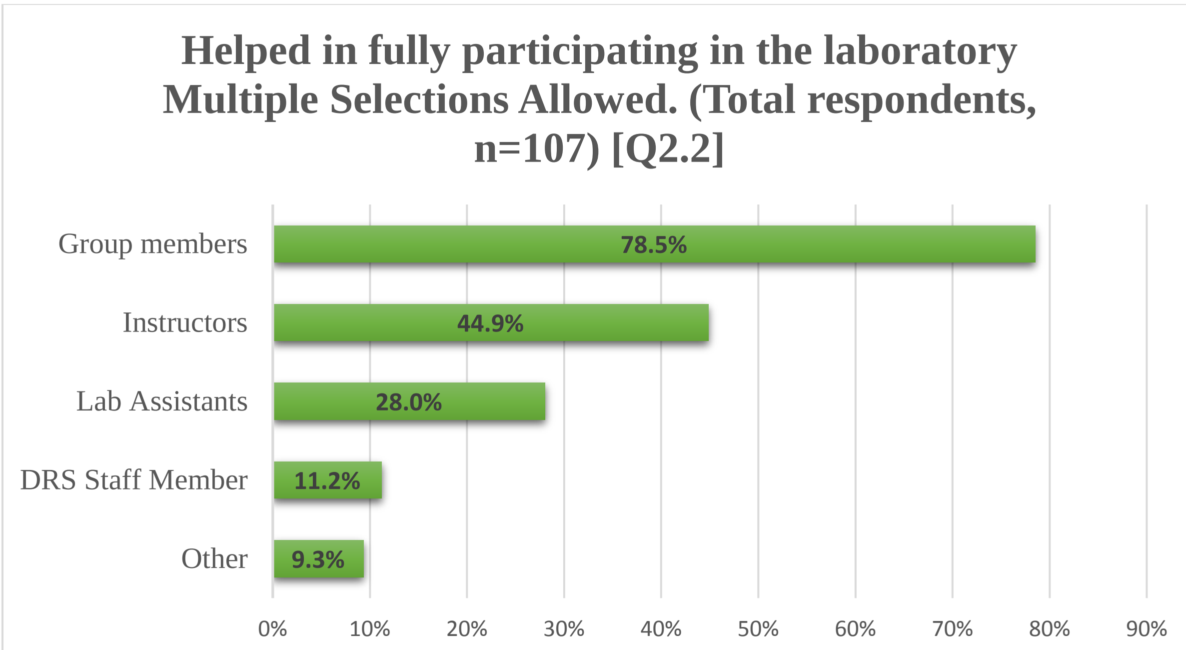

Figure 19. Helped in fully participating in the laboratory

5.3 DISCUSSION

This survey of over 100 participants identified some of the current challenges and solutions to participating in an S&E laboratory from the perspective of SwD-P. Majority of the respondents were college-aged Caucasian women with mobility impairments or difficulty lifting and carrying objects, who attended institutions from various parts of the U.S., within the past four years. Findings from the survey help to reduce the gap in research by offering evidence on barriers and facilitators to full participation in instructional S&E laboratories for SwD-P. The empirical data from the survey contributes to the S&E accessibility literature on barriers and facilitators with perceived insight directly from SwD-Ps within the BE, TE & LE domains that can impact SwD-Ps future success.

5.3.1 Contributions to S&E Accessibility Literature on Facilitators

The previous chapter provided credible evidence that there is a need to modify existing strategies for full participation in instructional S&E laboratories to assist SwD-P. Ramps, curb cuts, elevators and doors serve as facilitators to accommodating to accessing the laboratory space. Pertaining to TE, course materials were regarded generally accessible. Regarding LE, instructors were willing to help, but were not familiar with methods to help SwD-P.

5.3.1.1 Facilitators: BE

Ramps and elevators are arguably the best facilitators in getting into the laboratory. Miner and colleagues [10] developed a manual on teaching SwD in Chemistry. They argue that architectural accessibility is key to ensuring effective laboratory experience for SwD-P and mandate the need for an elevator to enter the laboratory. This mandate supports our findings on the ease of use of facility features such as elevators. Miner et al. [10] also argue that most academic institutions have complied with federal laws that require the elimination of physical barriers. However, our study points out that even though physical features such as ramps and curb cuts are helpful, many participants reported them to be non-existent.

Once inside the laboratory space having cleared aisles and having accessible laboratory amenities (e.g., accessible sinks) helps to level-the-playing field and complete laboratory tasks. A large (47%) portion of the verbal comments in the open-ended question on barriers to maneuvering in the laboratory was related to obstructive aisles and pathways. For example, one participant mentioned, "*path not straight, parts of machines projecting into aisle*." This was echoed in Miner et al.'s manual for chemistry students where students should be able to navigate aisles, specifically for wheelchair users who would need clear aisles [10]. Instructors becoming more mindful of cleared aisles may help to removing barriers to accessing equipment and other parts of the laboratory.

When working at a laboratory workstation, positioning equipment within reach can help SwD-P fully participate in laboratories. This modification would allow SwD-P to independently do things and rely less on lab partners; this slight modification may reduce the time needed to complete laboratory tasks, and can help avoid awkward positioning as one participant mentions "*needed to put my head into the fume hoods to reach the back.*" Moving smaller portable items can alleviate enormous burden such as moving a power strip, as one mentioned: "*The power strips were placed fairly high*...". In a chemistry laboratory, students must be able to use lab benches, fume hoods and other equipment [10]. Duerstock et al. [86] developed a technique to serve as a facilitator, called a, a work triangle consisting of a fume hood, sink, and workbench for easy access to frequently used machines in a biomedical laboratory. Instructors can work with administration for feasibility of a work triangle to promote an accommodating environment.

Having accessible laboratory amenities in the laboratory workspace such as accessible workstations, countertops, accessible faucets, and cabinets are critical to helping ensure full participation in the laboratory space. As noted by Duerstock and colleagues [86] water (e.g., faucets) gas (e.g., fume hoods) amenities should be in accessible locations. Location of these amenities is important for SwD-P, as one participant noted: "*The faucets could have been placed more toward the outside of the sink where it would have been easier to reach them.*" In a biomedical laboratory simulated environment, Duerstock and colleagues [86] convey how shallow sinks, and faucets moved closer to the user would be beneficial. While expecting adjustable height tables to be facilitators for the physical laboratory space [42], however, our results reveal that height adjustable tables were not easy to use for SwD-P. Only one participant left commented on this mentioning that height-adjustable tables are helpful: "*In each of my classrooms, there were adjustable height tables installed for use. In labs, this was not the case but would have helped immensely*. It would help to get further insight from SwD-P qualitatively to help understand why adjustable tables were not easy to use.

Safety is important to use a laboratory. On average respondents responded positively to safety procedures being addressed, such as accessible emergency exits (59%), shower pulls (49%), and having an accessible emergency eyewash basin (56%). This safety concern is also echoed in Miner et al. [10] manual in that emergency exits and showers must be accessible. Hilliard et al. [37] go further in mentioning that not only does easily accessible emergency exits, and showers serve as facilitators but go deeper to explain how (e.g. *an emergency eyewash basin moved further away from the supply line for easier access*). The survey did not go in depth to ask how these served as facilitators but confirmed that these safety features were addressed and were helpful.

5.3.1.2 Facilitators: TE

Majority (83%) of respondents reported that laboratory course materials (e.g., instructions and information) were accessible enabling participation in lab activities, a major improvement from over 20 years ago. Just a few years after the ADA was enacted there was still difficulty accessing documents in alternative formats [36]. One respondent who positively agreed noted that through the help of others "*...I worked with the techs to create an item used in my experiments*." Another respondent commented that "*The instructions required computer access*." A decade after the ADA was enacted Burgstahler and Nourse [88] reported that laboratory materials were difficult to access if not electronic. Electronics have improved over the years in short time from the use of Smartphones, tablets, dictation software that enables access to information more readily in more recent years than 20 years ago. Although we did distinguish whether the laboratory materials were electronic are not, this distinction may be used in a follow-up study. One respondent who did not agree with the survey question provided insight to help understand that non-electronic laboratory is still difficult to access: "*Lab book (a hardcover textbook with experimental procedures) was so heavy I couldn't bring it with me. We had to write out lab reports by hand in the lab notebooks, and it took me hours every day because I couldn't hold a pen easily.*

5.3.1.3 Facilitators: LE

A majority of the students had a positive perception of their S&E instructors. Some students who provided positive remarks, may not have had the actual experience, as one student (who had difficulty sitting, kneeling, squatting or bending) wrote: "*I didn't need assistance at all/not obvious that I have a disability, but I would say that the instructor and others would be inclusive if they knew*." Some of the strategies that helped, were instructors encouraged student's abilities, were inclusive in their behavior, and were respectful in their and were language. One participant mentioned "*[instructor's name was removed] from MSU Organic Chemistry Lab was the most helpful individual I have ever worked with in a laboratory setting. She quickly understood my* *condition, recognized my intense efforts to study and understand the material, and was more than willing to help me assemble certain apparatuses.*"

Another strategy found useful were peers and group members, both non-lab partners and lab partners were useful in completing laboratory tasks. Two comments from the survey provided additional insight to this facilitator stating: "*Occasionally a non lab partner would assist me in attaining Laboratory materials*," "*Inclusive and helpful classmates were EXTREMELY helpful and noticeable*." Future recommendations for instructors is to continue supporting SwD-P to be paired with helpful lab partners to help participation that requires hands-on activities [36], [43], [45].

5.4 CONCLUSION

The findings of this study highlight perceived facilitators SwD-P encounter in instructional S&E laboratories and can help drive research and development work. As identified in this study some helpful accommodations to getting to the laboratory include elevators, ramps and curb cuts. Once inside the laboratory most find course materials accessible and that non-adapted technology was found helpful to complete laboratory courses (e.g., digital recorders). When it comes to interaction with instructors and peers, most found teachers were willing to help. Yet more participants found their peers and group members to be more helpful. This research warrants further studies of facilitators in the postsecondary instructional science or engineering laboratory setting.

6.0 CONCLUSION, CONTRIBUTION AND FUTURE RECOMMENDATIONS

Previous investigations on barriers and facilitators to science and engineering (S&E) laboratories have not concentrated on postsecondary instructional S&E laboratories, and what is known about the topic is largely anecdotal. As a result, the experiences of students with physical disabilities who seek to learn in these labs remain largely unknown. In effort to address this gap in the literature, the present study the examined barriers and facilitators to students' (N=107) ability to fully utilize the science and engineering laboratories on their campuses. In an effort to contribute to the extant literature, the present study: 1) comprehensively reviewed past research on the topic, 2) developed and assessed the psychometric properties of a survey designed to examine barriers and facilitator to S&E instructional laboratories, 3) and presented empirical data on the perspectives and experiences of past and present postsecondary students with physical disabilities (SwD-P).

6.1 RECOMMENDATIONS

Findings from the current study suggest practices and recommendations for (1) college science and engineering instructors and laboratory assistants, (2) college institution administration and (3) students with physical disabilities in postsecondary instructional science or engineering programs.

6.1.1 College science and engineering instructors and laboratory assistants

6.1.1.1 Built Architectural Environments (BE)

The results of the survey indicate that SwD-P have successfully enrolled in two and four-year colleges and universities to take science or engineering laboratory courses taught by S&E instructors. Instructors can help avoid obstructive pathways once inside the laboratory as echoed by the National Science Teachers Association (NSTA) online literature, to keep aisles cleared when possible, move desks and chairs to widen aisles [90].

6.1.1.2 Task Execution (TE)

To help avoid SwD-P from taking on passive roles (e.g., observing), and to encourage them to become a more active participants, instructors can modify their curriculum or procedures to actively engage students with all parts of the activity [90]. More specifically, instructors should not assume or force an accommodation on a student, rather, assist them only when needed [90]. This can be done by finding out from SwD-P what type of assistance is needed; as one participant mentioned: "*I did not require physical assistance, only accommodations for written work.*" At the same time, instructors can help students understand that they can receive help at the beginning or prior to the start of a course, as one participant noted: "*I was unaware at the time that I could receive help*."

6.1.1.3 Learning Environment (LE)

Successful students found that encouraging instructors help them to get through their laboratory experience. Instructors should expect to have SwD-P matriculate in their instructional laboratory just like any other student. Instructors should be intentional from discouraging SwD-P to continue in S&E related fields, which may deter SwD-P from completing S&E programs. One participant mentioned: "*A large part of the reason why I discontinued biology as a major was because one of my instructors told me three weeks into a course that accommodating me would be too expensive and unfair to other students.*"

Findings from the survey indicate that SwD-P do not have enough time for laboratory setup. One way to address this as noted by online resources from University of Illinois Disability Services is to have students come in earlier for laboratory setup [91]. Additionally, instructors should continue to support group-based learning as shown in this study and another study that peers and labmates benefit from laboratory participation [92].

6.1.2 Policymakers, college science and engineering programs, and university administration

The new bill, currently under review (H.R. 620) to amend the ADA of 1990, is proposed to require demand letters to provide for a notice and a cure period prior to civil law suits can take place. Section 2 of H.R. 620 mentions that the Disability Rights portion of the Department of Justice (DoJ), property owners, and a disability rights advocate should work together to develop a program or train professionals to educate others on barrier removal strategies in areas that may potentially violate the ADA. The literature and the research study indicates that instructors are willing to help students with physical disabilities but do not know how to do so. Any help that students get should involve asking students about what they consider the barrier or facilitators to be. This bill should include developing strategies to assist school administrators and instructors in improving the accessibility of academic facilities, laboratory courses, and curricula. The following three strategies would assist science and engineering college instructors with developing hands-on training in a laboratory setting for students with physical disabilities by involving the students who would be using the laboratory.

1. Disability Rights portion of the DoJ, college and engineering program administration, disability services on campus, and a student with physical disabilities, should work together to develop a program to train instructors in how to accommodate students with physical disabilities who enter the courses.

2. To avoid SwD-P from taking on passive roles (e.g., observing), the administration can provide training to instructors to enable SwD-P to be more active. College science and engineering programs can partner with professional organizations such as the American Society of Engineering Education (ASEE), American Association for the Advancement of Science (AAAS) or Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) to provide professional development workshops on campuses or at their annual meetings for college instructors on disability etiquette in engineering laboratory spaces. These professional organizations may possibly be able to provide continuing education credit or credit towards professional development for college instructors. Ultimately this experience would build awareness around laboratory issues and potential accommodations that instructors can address to help ensure students with physical disabilities are provided with hands-on training in their laboratories. Moreover, professional development can also come from the university administration initiatives or

disability services office on campus. Norman and colleagues' [18] study of science courses find that 95.2% of college science instructors believed that all instructors of science should be required to be trained in teaching science SwD [18].

3. These professional organizations (.e.g., RESNA and ASEE) can also serve as a medium to train and teach professionals such as “Certified Access Specialists” (as mentioned in the bill) to help provide guidance to college institutions and collaborate with disability resource services on college campuses to ensure students are fully participating in science and engineering laboratories

In section 3 of the H.R. 620, the timeline to address barriers should be shortened. There is no accountability to ensure that "enough" progress will be made in the two months, usually colleges and university courses are 15 weeks long, or 75 class days, 60 days into the semester or quarter, the course is already almost over and the next student may have to go through the same issues as well. Not only the physical environment, but also attitudinal barriers continue to be an issue, which should be considered. Instructors should have sensitivity training or university administration should have strategies in place to ensure students are not discriminated against. Instructors should expect to have SwD-P matriculate in their instructional laboratory just like any other student. Instructors should be cognizant of any biases that discourage SwD-P from continuing in S&E related fields, thereby deterring SwD-P from completing S&E programs. One participant mentioned: "*A large part of the reason why I discontinued biology as a major was because one of my instructors told me three weeks into a course that accommodating me would be too expensive and unfair to other students*." Another participant shared insight on how negative attitudes can be a stumbling block “*Disability services was condisending [sic] and recommended that I should consider not completing my degree as the result of my health developments. I'm now*

7/8 of the way done with my degree and two minors as the result of my hard work and a number of friends that assist me with tasks that I would otherwise be unable to complete. There have also been a few lab TA's that have helped me through some of my more difficult labs; however, there was not help given at the Chemistry lab and I (along with several other disabled students) was strongly discriminated against by our Organic Chemistry Professor. This is why I've been unable to complete this course (required for my degree)."

In Section 5 of H.R. 620, not only a representative of the disability community should help develop alternatives to litigations, this should also include students with physical disabilities, since they have the direct impact. As of now the data from the survey indicates that changes have still not been made getting into the laboratory space. Several individuals (24%) who have taken this nation-wide survey indicated that there are signage and physical barriers reaching the laboratory space, most of which reported that these barriers happened between 2013-2017, which is over 25 years since the original bill was passed. Once inside the laboratory space, individuals found it difficult to maneuver and get to the machines due to unclear aisles or overcrowded areas.

Successful universities have made efforts to provide accommodations and resources to help students with disabilities. Another suggestion is for the department to hire hands-on laboratory assistant. As a participant noted "*The department hired someone to "be my hands" and do the physical tasks that I could not.*"

6.1.3 Students with disabilities

6.1.3.1 TE

Students should be encouraged to voice any concerns, make accommodations or adjustments themselves to participate in the laboratory activity. One participant noted "*No interventions were* *really necessary, I just modified things myself when needed, which wasn't often*." Students may be able to contact Disability Resource Services on their local campus to obtain needed support. As one participant stated, "*I was able to get accommodations through the University which provided me with a stool to sit on*."

6.1.3.2 LE

Students can initiate support by self-advocacy. Another participant mentioned that "*Despite having a detailed list of accommodations with the university, the assistive technologies and modifications were only initiated by me speaking up to the professor. This process makes me somewhat reluctant to speak with an unknown professor out of embarrassment and not wishing to draw extra attention to myself.*" This piece of information provides insight that some instructors may be privy to accommodations to SwD-P, given the university has already provided information or training to instructors and that instructors are ready to provide accommodations once approached.

6.2 LIMITATIONS

Despite the contribution to the existing knowledge base on barriers and facilitators of science and engineering laboratory use by students with physical disabilities, the study had a number of limitations. First, in the absence of comprehensive lists of students with physical disabilities from the organizations and institutions from which I collected data, I used a convenience sampling strategy for data collection. As a result, it is not possible to generalize the results of the study beyond the students who completed the survey. There was no clear way to verify who distributed the survey. Some organizations and schools may not have been involved if gatekeepers from that particular institution or organization did not disseminate the survey. This could have limited the number of participants who could have decided to take part in the survey. For the reliability portion of the survey, the respondents were not forced to answer each item, which made it almost impossible to analyze test-retest for a number of items. A future consideration for surveys would be to implement a forced response for test-retest protocols.

While there were over 700 respondents who consented, 228 respondents met the inclusion criteria. Because the survey was online and it was connected to social media, the overall participation might have been influenced by the social-networking aspect of the on-line recruitment process. Another possible explanation for the early attrition could be that these individuals may not have taken the time to fully reviewed the consent form, and just wanted to get to the questions. Another possible explanation is that the respondents may not have been clear that they needed to meet all the inclusion criteria to complete the survey. Another possibility is that individuals may have been induced by the small monetary incentive in that they might have tried to get through the survey to obtain the $25 incentive, this may speak to the few individuals that completed the survey in a short time (<6 minutes).

The research study was primarily quantitative and partially qualitative (i.e., selected questions had open ended responses), allowing participants to provide rich content that is often found in focus groups and intensive interviews. Focus groups have some advantages as well, such as, allowing a group of persons to interact and share ideas [67]. The survey data can only be interpreted by choice selection on a Likert scale or text from open-ended items. People were not forced to provide comments for every question in the survey. Because follow-up was not allowed, participants who chose not to answer or had terse feedback increased the difficulty of interpretation behind their choices. Additionally, the not applicable (N/A) option on Likert-scale, may be difficult to interpret for certain questions because there were more than one reason assigned for the option (e.g. The following made it easy to use the laboratory space. Select 'Not Applicable' if the situation did not apply or the feature did not exist). In future studies, each option should be specific and should avoid using ‘or’ to make interpretation easier for analysis.

This particular research targeted alumni and current students. Possible future research may focus on current students alone or alumni alone. Additionally, this survey was also only limited to past students with physical disabilities, future work can focus on other impairments such as (cognitive or sensory) to find barriers and facilitators that can work for specific impairments.

Online surveys are a commonly proposed method for exploratory and descriptive research [93]. Moreover, online or mobile surveys are best used for non-probability or convenience sampling and less appropriate for probability sampling [93]. Online surveys are found to be more cost-effective and efficient compared to mailing surveys or phone interviews. There are several advantages to using online surveys. The use of online help to reach people with disabilities who would otherwise be difficult to reach [94]. The use of online surveys is best to target a large number of participants who are widely distributed geographically and provides a quick turnaround time to receive the data [94]. Online surveys also allow a person to complete the survey at their pace and convenience [94]. Johnson, [94] recommends that respondents with disabilities should be allowed to log-off and return and finish surveys at their own pace. Using an online platform such as Qualtrics allows for users to leave the survey and return and finish at a later time as long as the survey link remains open on a tab on their device. Moreover, data entry occurs automatically, eliminating the need to hire others to collect and enter data [94]. From a technical standpoint for survey designers, the online platform allows for skip patterns, which can reduce the number of questions that respondents can see when taking the survey. Regarding individuals with different abilities, using online surveys allows individuals to continue using technology they are already familiar with when connecting with the online web to complete the survey without needing to use additional technology to complete the survey. This ease of use reduces any difficulty in accessing the survey for individuals with different impairments. A wide range of assistive devices can be used to replace computer keyboards and mice to help users with limited used of their hands (e.g., alternative keyboards, speech recognition software) [94]. Platforms such as Qualtrics allows survey designers to run accessibility tests to ensure the survey is section 508-compliant prior to launch.

Online surveys have disadvantages as well. When the survey is anonymous, respondents can abandon the survey at any time, and there is no way to find out why or encourage the individual to finish [93]. Another disadvantage of using on-line surveys if individuals are not technologically savvy or regularly use the internet, one might not be able to reach them, therefore, making it difficult to reach everyone in the population [93]. In sum, online surveys are accessible only to those who have access to the internet. This lack of access reduces the chance that the researcher is able to truly capture a representative sample of the population of interest. Other disadvantages of using online surveys occur when submitting an Institutional Review Board (IRB) application. The IRB language and items for human subject protections may be antiquated and are not suitable, adaptable and applicable for online research. For example, the language on recruitment used in the IRB application can be inappropriate, misleading, or difficult for the would-be researcher to provide accurate responses since one does not have unlimited control once the online survey is disseminated.

The following section will discuss Section 3 of the IRB application. Other parts of the IRB original protocol could and should also be revised to reflect future studies that may be geared towards online presence such as nationwide online surveys. For example, section 3.11 of the IRB application asks: "What is the total duration of the subject's participation in this research study across all visits, including follow-up surveillance?" Given that the inclusion criteria focus on individuals with a physical disability, along with the survey platform, one can only make an educated guess as to the length of time an individual with a physical disability will spend answering the survey. In addition, once the survey is disseminated, given Johnson's [94] recommendation described earlier, it is expected that the survey may take an individual with certain disabilities much longer to complete than the average completion time. Moreover, that Qualtrics allows a respondent to walk away from the survey to be completed at a later date begs the question of whether this question can apply to an online survey. Items 3.10 and 3.11 asks to record the number of participants. It would be more appropriate if current language for item 3.11 "Identify each of the disease or condition specific subgroups (include healthy volunteers, if applicable) that will be studied" would be changed to "identify specific subgroups (include participants used in control group, if applicable) that will be studied." With a mail back survey or a face-to-face survey this question would be appropriate but with a convenience or snowball sample using online recruitment there is no way to identify the number of participants until the survey has been completed. Under item 3.11, within the current IRB application, one should select "subgroup" and enter the type of sample population, although in some situations the term "target population" would be more appropriate, enter a name for the sample population for example "past and present students with physical disabilities." Under the section "Numberto undergo research procedures:" here the number of individuals who are expected to complete the survey for analysis should be recorded (e.g., 200). A challenge is created if more people complete the survey than expected, which would result in reporting to the IRB a Deviation or Non-compliance from the protocol. A similar situation can occur when more individuals complete consent to take the survey than expected, which is out of the control of the investigator. Under the section "Number to undergo screening procedures" one should record how many individuals are expected to consent, this number exceeded the current study's expectation which resulted in reporting a deviation from the protocol which led to another IRB modification. To prevent this from happening one should report a number, ten times the number expected to avoid reporting a deviation from the protocol and IRB modification (e.g., 2000). Similarly, for an IRB application renewal under section 3.1 "Enrollment Numbers," here the IRB redisplays the value from the original IRB application under "Total number of subjects approved by the IRB for entire duration of study (including subjects to be screened): (e.g. 2000)." Also displayed is the "Total number of eligible subjects approved to undergo research related procedures (target enrollment): (e.g., 200)" In the section 3.1, under the IRB renewal, One must enter the following: A) "total number of subjects enrolled", B) "Subjects deemed ineligible after signing consent," C) "Subjects currently active on study or in follow-up," D) "Subjects withdrawn at their own/family request (e.g. subject signed consent and then changed mind or stopped at their request)," E) "Subjects withdrawn by PI due to toxicity or adverse events," F) "Subjects withdrawn by PI due to other reasons (e.g., lack of compliance, pregnancy, death due to disease progression)," G) "Subjects lost to follow-up," and H) "Subjects who completed the study." Most of these do not correspond with normal procedures for an online survey. For A, the total number of respondents enrolled would correspond best with the number of respondents who consented to take the online survey. For B, subjects deemed ineligible only works best if you have screening questions after the “consent” portion of the online survey. C, may not apply if there are no pending surveys, which means a person started the survey, but did not complete the survey yet and are still within the completion time window if set. D and E may not apply to online surveys at all. For F, one can record the number of respondents individuals who are removed from analysis due to patterns of missing data, short completion time or any other reasons the investigator may not find their data to be compromised for analysis. G is a little difficult to respond to, although no participants are lost to follow-up for single cross-sectional study design, there is nowhere else to report the participants who completed the screening questions but did not complete the survey. In, H, one should report the number of individuals who were used for analysis. B-H, should all add up to the number of those enrolled (A) in the study. I believe this section should be different for online surveys. What should be reported in this section is A) the number of participants who consented, given there is a consent portion of the survey; B) the number of individuals who completed the screening process, given there are screening questions; C) the number of individuals who completed the screening questions but did not complete the survey and D) those who were removed from the analysis; and E) those who were used for analysis.

6.3 FUTURE WORK

Future studies should continue to sample academic institutions, advocacy groups, and science and engineering companies. Online surveys helps to access a large number of respondents who are geographically dispersed in a short time, however there may be part of the sample who may be more difficult to reach (e.g., those who are not technologically savvy or seldomly use the internet). Regarding gender, this study was relatively proportionally similar to gender in the population, in which there were more females than male respondents. The NCES reports indicate that in the population there are more females (2.4%) than males (1.8%) who are undergraduates with a physical disability [7]. Pertaining to race, in this survey there was about eight times as many White or Caucasian respondents than any other race. In the population there are more Blacks (14.1%) than Whites (13.9%) and Hispanics/Latinos (13.4%) who are undergraduates with a physical disability [7]. One might try to target predominantly Hispanic-serving institutions or historically black colleges (HBCU's) to increase the number of underrepresented groups. However, this may not be appropriately representative since information provided may only stem from the experiences at Hispanic-serving institutions and HBCU's and may not represent experiences at R1 institutions. One way to possibly increase the number of underrepresented groups may be to provide additional incentive for underrepresented groups who fill out the survey at certain institutions (e.g. R1). More importantly, targeting student-professional organizations would be beneficial such as the National Society of Black Engineers (NSBE), Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS), and Society of Hispanic Professional Engineers (SHPE). These organizations serve as a platform to reach underrepresented students from various institutions (e.g. R1-R3 institutions).

6.3.1 Further validity and reliability of the survey

The small sample size (n=20) for test-retest may have impacted our data analysis, while other studies used reliability sample sizes larger than 100 participants. Although the FPSEA Survey had adequate psychometrics, additional psychometric studies may be even more insightful. Future reliability and validity studies are suggested to have a larger sample size.

6.3.2 Severity of the barriers

It would be helpful to directly ask about the severity of the barrier to understand to what extent the barriers cause a hindrance. This information would be beneficial to instructors and university administration if there were empirical data on the level of severity of barriers grouped by the person's level of function. One might attempt to infer severity from the current data set by looking at the number of individuals selecting an extreme on the 5-point Likert scale to aisles not being cleared. It may be appropriate to have a follow-up survey to rate the level of difficulty or severity of the barrier, to help administrators and instructors understand how to prioritize the barriers based on the students' needs to fully participate in the laboratory.

6.3.3 The complexity of the facilitators

Certain facilitators may be less complex than others to help create the fully inclusive environment. Built Environment facilitators that may be more complex (e.g., monetary, contractors) would include ensuring that elevators, ramps, and curb cuts are installed to get into the laboratory space. When executing tasks within the laboratory space, full participation may be encouraged by instructors and university administrators who may agree that certain laboratory features are installed to help operate laboratory equipment based on the findings from this research study: single action levers, mirrors, camera systems, and tools to help reach parts of laboratory equipment. Other resources that were helpful to operating laboratory equipment were computer simulations and operating laboratory equipment remotely. Instructors may find remote access to a laboratory or existing simulations to be helpful such as Purdue University's Accessible Biomedical

Immersion Laboratory (ABIL) [24]. The facilitators include regarding the interaction between students and instructors, may include less complex facilitators such as universities helping to set up training sessions for instructors to teach and interact with students with disabilities that may enter their classroom. The university may already have existing resources, which may not cause a financial burden to the institution to mandate or incentivize instructors to go to training on campus or at a local conference with AAAS or ASEE. The university administration can provide education on available resources to students with physical disabilities and provide training that empowers users to advocate for themselves which are important to successfully acquire appropriate accommodations for full participation [95]. This can be done through disability resources services or initiatives and programs that can come from the provost or dean of student's office.

6.3.4 Faculty Training Protocol

One of the main conclusions from the study is that postsecondary instructors (e.g., faculty, teaching assistants) are willing to help but do not know how to help assist students with disabilities in the laboratory environment. Faculty members are often inundated with various activities (e.g., research work, teaching courses and taking on students). Training faculty can start from building awareness down to having faculty having full-blown engagement with SwD-P to help reduce barriers in science and engineering laboratory settings. Awareness can be achieved in various stages, the first level of consciousness starts with providing brochures or online literature to instructors on barriers SwD-P may encounter in S&E laboratories. University of Washington's Disabilities, Opportunities, Internetworking, and Technology (DO-IT) Center, has spent considerable effort towards making resources available for campuses to become more equitable and accessible, and teaching instructors to be more confident in teaching for students with disabilities. Online training literature provided by DO-IT, can help give a foundation on accessibility <https://www.washington.edu/doit/resources/comprehensive-training-materials>. Online webinars or videos can also build awareness, for example DO-IT has a database of videos on making classroom environments more accessible <https://www.washington.edu/doit/do-it-videos>.

The second level of awareness involves building a workshop into the schedules of faculty, which may be a little more engaged. For example, have a 15-minute seminar or presentation as part of the new faculty orientation. Another example would be to have faculty and teaching assistants to attend a one-hour luncheon panel discussion (food and room provided by the department and encouraged by the department head). In this session, past SwD-P who have taken a science or engineering course would sit on a panel to discuss their past experiences. Faculty would be incentivized to attend the luncheon, or directly ask questions to the students on the panel on barriers and facilitators SwD-P encounter. A third level of awareness would include full engagement between faculty members, teaching assistants and students with physical disabilities. For example, have a workshop that would serve as a simulated environment, where instructors would work with students to define the challenges and work together to come up with solutions to remedy barriers. Another example would be for instructors to use the Engineering laboratory accessibility checklist developed by DO-IT and report on their findings <https://www.washington.edu/doit/checklist-making-engineering-labs-accessible-students-disabilities>.

6.3.5 Expansion of work

The Americans with Disabilities Act (ADA) Network, may also benefit from this work. The information may be shared with the ADA National Network to help establish a checklist that can be used to assess STEM laboratories. Checklists serves various fields from medicine to disaster recovery and has shown to improve communication between stakeholders [96]. The field of medicine has shown and supported the use of checklists [96]. From this work, a checklist from the ADA may be developed to objectively, determine whether science or engineering laboratories are accessible to students with physical disabilities.

Another branch that may have similar laboratory settings and benefit from the survey would be institutions such as the Association of American Medical Colleges (AAMC) which serves medical students in their laboratory experiences. Work has already started from the University of Michigan and the University of California San Francisco (UCSF) to help inform instructors and researchers in the medical school on enrolling and retaining students with disabilities. This survey, or a similarly developed survey may be used to help inform medical instructors on barriers and supports medical students with physical disabilities may encounter in the hands-on laboratory experience in medical school, and may even expand to medical residents with physical disabilities.

APPENDIX A

SURVEY

STEM_Accessibility_Survey_Final

Start of Block: Consent and Demographics

X→

Q1.2 Have you read the above consent and agree to take this survey?

- O Yes (1)
- O No (2)

Skip To: End of Survey If Q1.2 = 2

X→

Q1.3 Are you 18 years of age or older?

- O Yes (1)
- O No (2)

Skip To: End of Survey If Q1.3 = 2

X→

Q1.4 Do you have a physical impairment that affects your arms or legs?

O Yes (1)

O No (2)

Skip To: End of Block If Q1.4 = 2

Q1.5 Are you currently or have you been enrolled in a science or engineering related course at a college, university or technical school?

O Yes (1)

O No (2)

Skip To: End of Block If Q1.5 = 2

Q1.6 Have you previously completed this survey?

O Yes (1)

O No (2)

Display This Question:

If Q1.6 = 2

Q1.7 Would you be interested in a follow-up survey (which will be sent to you within two weeks after completing this survey)?

O Yes (1)

O No (2)

Q1.8 Please provide your details below:

- O First Name (1) ____________________
- O Last Name (2) ____________________
- O Email Address (3) ____________________

Display This Question:

If Q1.6 = 2

X→

Q1.9 In which of these activities do you have severe difficulty doing without assistance? Check all that apply.

- ▢ Standing (1)
- ▢ Walking (2)
- ▢ Climbing stairs (3)
- ▢ Sitting, kneeling, squatting, or bending (4)
- ▢ Crawling (5)
- ▢ Lifting or carrying objects in hands or arms (e.g. gallon of paint) (6)
- ▢ Picking up or putting down objects (7)
- ▢ Grasping a tool or door knob (8)
- ▢ Using fingers to handle small objects (e.g. coins) (9)
- ▢ Pulling door closed or pushing objects away (10)
- ▢ Reaching objects (11)
- ▢ Twisting, rotating, bending an object (e.g. using tools) (12)
- ▢ None of the above (13)

Skip To: Q1.25 If Q1.9 = 13

Display This Question:

If Q1.6 = 2

X→

Q1.10 What is the nature of your disability or diagnosis, if you have one (e.g. physical disability)? Select all that apply.

- ▢ Paraplegia (1)
- ▢ Tetraplegia/Quadriplegia (2)
- ▢ Absent limb/reduced limb function (3)
- ▢ Spina Bifida (4)
- ▢ Multiple Sclerosis (MS) (5)
- ▢ Cerebral Palsy (CP) (6)
- ▢ Muscular Dystrophy (MD) (7)
- ▢ Other (8) ____

Display This Question:

If Q1.6 = 2

X→

Q1.11 What is your gender?

- O Male (1)
- O Female (2)
- O Other (3)
- O I prefer not to answer (4)

Display This Question:

If Q1.6 = 2

X→

Q1.12 What is your ethnicity/race?

- O White, non-Hispanic (1)
- O Black/African-American (2)
- O Hispanic/Latino (3)
- O Asian (4)
- O American Indian/Alaskan Native (5)
- O Native Hawaiian/Pacific Islander (6)
- O Multi-race (not Hispanic/Latino) (7)
- O Other (8)
- O Prefer not to answer (9)

Q1.13 What is your year of birth (YYYY)?

____

Display This Question:

If Q1.6 = 2

Q1.14 What year did you acquire a physical impairment (YYYY)?

____

Display This Question:

If Q1.6 = 2

Q1.15 Are you currently in school (e.g. college, technical school, etc.)?

O Yes (1)

O No (2)

Skip To: Q1.18 If Q1.15 = 2

Display This Question:

If Q1.6 = 2

Q1.16 What degree are your currently pursuing (e.g. B.S. Physics) ?

____

____

____

____

____

Display This Question:

If Q1.6 = 2

Q1.17 When do you expect your degree, if you are currently a student (YYYY)?

____

Display This Question:

If Q1.6 = 2

Q1.18 Please select all degrees you currently hold, your major and year of graduation (e.g. B.S. Physics, 2005; B.S. Electrical Engineering, 2010)?

- ☐ High school diploma/ GED (1) ____________________
- ☐ Associates (2) ____________________
- ☐ B.S./B.A., etc. (3) ____________________
- ☐ M.S./M.A., etc. (4) ____________________
- ☐ Ph.D., etc. (5) ____________________
- ☐ Licenses (6) ____________________

Display This Question:

If Q1.6 = 2

X→

Q1.19 In which type of school have you had the most experience using a science or engineering laboratory?

- O Community College (1)
- O 2-year Technical College (2)
- O 4-year College or University (3)

Display This Question:

If Q1.6 = 2

Q1.20 What was/is the name of your school?

____

Display This Question:

If Q1.6 = 2

Q1.21 What is your current employment status? Check all that apply.

- ☐ Student (1)
- ☐ Employee (2)
- ☐ Self-employed (3)
- ☐ Out of work and looking for work (4)
- ☐ Out of work but not currently looking for work (5)
- ☐ Military (6)
- ☐ Retired (7)
- ☐ Unable to work (8)
- ☐ Never worked (9)

Display This Question:

If Q1.6 = 2

Q1.22 Rate the accessibility of all the science or engineering laboratories with which you have had experience. If no experience select 'Not Applicable.'

	Very accessible (1)	Somewhat accessible (2)	Not Applicable (3)	Somewhat inaccessible (4)	Very inaccessible (5)
Machine Shop, Plastics and Metals (Q1.22_1)	O	O	O	O	O
Chemistry (Q1.22_2)	O	O	O	O	O
Biology (Q1.22_3)	O	O	O	O	O
Physics (Q1.22_4)	O	O	O	O	O
Electrical or Electronics (Q1.22_5)	O	O	O	O	O
Mechanical Engineering (Q1.22_6)	O	O	O	O	O
Chemical Engineering (Q1.22_7)	O	O	O	O	O
Civil Engineering (Q1.22_8)	O	O	O	O	O
Other (Q1.22_9)	O	O	O	O	O

Display This Question:

If Q1.6 = 2

X→

Q1.23 Which science or engineering laboratory was the most inaccessible?

- O Machine Shop, Plastics and Metals (1)
- O Chemistry (2)
- O Biology (3)
- O Physics (4)
- O Electrical or Electronics (5)
- O Mechanical Engineering (6)
- O Chemical Engineering (7)
- O Civil Engineering (8)
- O Other (9) ____

Display This Question:

If Q1.6 = 2

Q1.24 What year did you have the laboratory experience that was most inaccessible? (YYYY)

____

Display This Question:

If Q1.9 = 13

And Q1.6 = 2

X→

Q1.25 Did you encounter any barriers in attempting to use STEM laboratory space?

- O Yes (2)
- O No (1)

End of Block: Consent and Demographics

Start of Block: End of Survey Question

Q2.14 Any last thoughts or additional comments you would like to share?

____

____

____

____

____

End of Block: End of Survey Question

Start of Block: Learning Environment

Q2.1 Learning Environment Section - These questions allow you to share your experiences when using a science or engineering laboratory. The next set of questions will pertain to the learning environment of the laboratory as it relates to the learning, communication (e.g. conversations with peers or instructors), and interpersonal interactions (e.g. lab assistance from instructors or others) that correspond with how information is exchanged in the laboratory space (as well as initiatives that can help instructors). This includes attitudes, opinions and beliefs of the students with disabilities from others (e.g. student peers, lab assistants and instructors).

Please answer the following questions for the laboratory (after receiving high school diploma or GED) that was **most problematic** or the lab that had the most barriers.

Q2.2 Who helped you in fully participating in the laboratory? Check all that apply.

- ▢ Instructors (1)
- ▢ Staff member from the disability service office (2)
- ▢ Group members or classmates (3)
- ▢ Lab assistants (4)
- ▢ Other (5) ____

Q2.3 Additional Comments for Q2.2

Q2.4 To what extent do you agree with the following statements regarding instructors or laboratory assistants while working in the laboratory space.

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Had knowledge in how to accommodate students with disabilities (Q2.4_1)	O	O	O	O	O
Practices were in place to accommodate students with disabilities (Q2.4_2)	O	O	O	O	O
Inclusive behavior (Q2.4_3)	O	O	O	O	O
Respectful and inclusive language (Q2.4_4)	O	O	O	O	O
Instructors encouraged student's abilities (Q2.4_5)	O	O	O	O	O
Instructor(s) worked with student to make accommodations (Q2.4_6)	O	O	O	O	O
Other (Q2.4_7)	O	O	O	O	O

Q2.5 Additional Comments for Q2.4

____

Q2.6 Assistance from colleagues and able-bodied peers (e.g. non-lab partner) **helped** in completing laboratory tasks

- O Strongly agree (1)
- O Somewhat agree (2)
- O Neither agree nor disagree (3)
- O Somewhat disagree (4)
- O Strongly disagree (5)

Q2.7 Additional Comments for Q2.6

____

Q2.8 Instructor(s) or laboratory assistant(s) were willing to accommodate your specific needs

- O Strongly agree (1)
- O Somewhat agree (2)
- O Neither agree nor disagree (3)
- O Somewhat disagree (4)
- O Strongly disagree (5)

Q2.9 Additional Comments for Q2.8

____

Q2.10 Instructor(s) believe in most cases, it is best if peers conduct a science investigation with the student with the disability as an observer

- O Strongly agree (5)
- O Somewhat agree (4)
- O Neither agree nor disagree (3)
- O Somewhat disagree (2)
- O Strongly disagree (1)

Q2.11 Additional Comments for Q2.10

____

Q2.12 Programs were available to help instructors be equipped and be better prepared to teach students with disabilities

- O Strongly agree (1)
- O Somewhat agree (2)
- O Neither agree nor disagree (3)
- O Somewhat disagree (4)
- O Strongly disagree (5)
- O Unknown (6)

Q2.13 Additional Comments for Q2.12

____

End of Block: Learning Environment

Start of Block: Built Environment

Q3.1 Physical Built Environment Section - The following questions pertain to the physical built environment (e.g. person changing physical location to access the laboratory space).

Please answer the following questions for the laboratory (after receiving high school diploma or GED) that was **most problematic** or the lab that had the most barriers.

Q3.2 There were physical or informational (e.g. entrance signage) barriers to reaching the building's main entrance (which houses the laboratory).

- O Yes (2)
- O No (1)

Q3.3 Additional Comments for Q3.2

____

Q3.4 There were physical barriers to the **entrance** of the **main building** (which houses the laboratory).

- O Yes (2)
- O No (1)

Q3.5 Additional Comments for Q3.4

____

Q3.6 There were physical barriers to the **entrance** of the science or engineering **laboratory**.

- O Yes (2)
- O No (1)

Q3.7 Additional Comments for Q3.6

____

Display This Question:

If Q3.6 = 1

Q3.8 The following were easy for you when entering the laboratory space (inside of the main building).
NOTE: Rate all that were present. If you did not encounter these items, select "Not Applicable."

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)	Not Applicable (6)
Operating Doors (Q3.8_1)	O	O	O	O	O	O
Operating Elevators (Q3.8_2)	O	O	O	O	O	O
Operating Platform Lifts (Q3.8_3)	O	O	O	O	O	O
Using Ramps or Curb Cuts (Q3.8_4)	O	O	O	O	O	O
Identifying signs to accessible entrance (Q3.8_5)	O	O	O	O	O	O
Other (Q3.8_6)	O	O	O	O	O	O

Display This Question:

If Q3.6 = 1

Q3.9 Additional Comments for Q3.8

____

Display This Question:

If Q3.6 = 2

Q3.10 The following features were barriers to you when entering the laboratory space (inside of the main building). NOTE: Rate all that were present. If you did not encounter these items, select "Not Applicable."

	Strongly agree (5)	Somewhat agree (4)	Neither agree nor disagree (3)	Somewhat disagree (2)	Strongly disagree (1)	Not Applicable (6)
Width of Doors (Q3.10_1)	O	O	O	O	O	O
Operating Doors (Q3.10_2)	O	O	O	O	O	O
Operating Platform Lifts or Elevators (Q3.10_3)	O	O	O	O	O	O
Curb Heights (Q3.10_4)	O	O	O	O	O	O
Having Stairs or Steps (Q3.10_5)	O	O	O	O	O	O
Other (Q3.10_6)	O	O	O	O	O	O

Display This Question:

If Q3.6 = 2

Q3.11 Additional Comments for Q3.10

____

Display This Question:

If Q3.6 = 2

Q3.12 You were able to enter the laboratory space despite any barriers.

- O Yes (1)
- O No (2)

Skip To: End of Survey If Q3.12 = 2

Q3.13 There were physical barriers in maneuvering or moving around the majority of the laboratory space

- O Yes (2)
- O No (1)

Q3.14 Additional Comments for Q3.13

____

Display This Question:

If Q3.13 = 1

Q3.15 The following accessible laboratory features were helpful:

	Yes (1)	No (2)	Not Present (6)
Accessible workbenches or workstation (Q3.15_1)	O	O	O
Accessible laboratory sinks and faucets (Q3.15_2)	O	O	O
Accessible countertops (Q3.15_3)	O	O	O
Accessible cabinets (Q3.15_4)	O	O	O
Adjustable table heights (Q3.15_5)	O	O	O
Accessible emergency exits (Q3.15_6)	O	O	O
Accessible shower pulls (Q3.15_7)	O	O	O
Accessible emergency eyewash basin (Q3.15_8)	O	O	O
Other (Q3.15_9)	O	O	O

Display This Question:

If Q3.13 = 1

Q3.16 Additional Comments for Q3.15

____

Q3.17 The following made it easy to use the laboratory space. Select 'Not Applicable' if the situation did not apply or the feature did not exist.

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)	Not Applicable (6)
Aisles cleared (Q3.17_1)	O	O	O	O	O	O
Accessible drawers and countertops (Q3.17_2)	O	O	O	O	O	O
Height-adjustable tables (Q3.17_3)	O	O	O	O	O	O
Raised platforms (Q3.17_4)	O	O	O	O	O	O
Lowered shelves (Q3.17_5)	O	O	O	O	O	O
Ramps (Q3.17_6)	O	O	O	O	O	O
Accessible sinks/faucets (Q3.17_7)	O	O	O	O	O	O
Power strips placed within reach of user (Q3.17_8)	O	O	O	O	O	O
Other: (Q3.17_9)	O	O	O	O	O	O

Q3.18 Additional Comments for Q3.17

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Display This Question:

If Q3.13 = 2

Q3.19 Please list barriers in maneuvering or getting around the laboratory space.

____

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Display This Question:

If Q3.13 = 2

X→

Q3.20 You were able to access the laboratory space despite any barriers.

- O Yes (1)
- O No (2)

Skip To: End of Survey If Q3.20 = 2

X→

Q3.21 When working at your laboratory station, all of the necessary equipment was positioned within your reach to allow you to complete the laboratory tasks.

- O Yes (1)
- O No (2)

Q3.22 Additional Comments for Q3.21

____

Q3.23 The following safety procedures were addressed in the laboratory environment (e.g. arrangements were made for emergencies). If the situation did not apply to your laboratory experience, select "Not Applicable."

	Strongly agree (1)	Not Applicable (6)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Accessible emergency exits (Q3.23_1)	O	O	O	O	O	O
Accessible shower pulls (Q3.23_2)	O	O	O	O	O	O
Accessible emergency eyewash basin (Q3.23_3)	O	O	O	O	O	O
Safety measures for handling hazardous materials (Q3.23_4)	O	O	O	O	O	O
Alternative arrangements for emergencies (Q3.23_5)	O	O	O	O	O	O
Other (Q3.23_6)	O	O	O	O	O	O

Q3.24 Additional Comments for Q3.23

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End of Block: Built Environment

Start of Block: Task Execution

Q4.1 Task Execution Section - These questions relate to executable tasks (e.g. setting up and executing tasks in a laboratory). This includes tools, equipment and computer resources for students

Please answer the following questions for the laboratory (after receiving high school diploma or GED) that was **most problematic** or the lab that had the most barriers.

X→

Q4.2 Was the majority of your participation limited to any of the following activities? Check all that apply.

▢ Note-taking (1)

▢ Writing papers (2)

▢ Programming software (3)

▢ Was not limited (5)

▢ Other (4) ____

Q4.3 Additional Comments for Q4.2

____

Q4.4 The laboratory course materials (e.g. instructions and information) were accessible, allowing you to participate in the laboratory activities.

- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Q4.5 Additional Comments for Q4.4

Q4.6 There were physical barriers in setting up laboratory experiments or projects

- O Strongly agree (5)
- O Somewhat agree (4)
- O Neither agree nor disagree (3)
- O Somewhat disagree (2)
- O Strongly disagree (1)

Q4.7 Additional Comments for Q4.6

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Q4.8 There was enough time allotted to independently setup laboratory experiments or projects

- O Strongly agree (1)
- O Somewhat agree (2)
- O Neither agree nor disagree (3)
- O Somewhat disagree (4)
- O Strongly disagree (5)

Q4.9 Additional Comments for Q4.8

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Q4.10 There were physical barriers to operating laboratory equipment to perform laboratory tasks

- O Strongly agree (5)
- O Somewhat agree (4)
- O Neither agree nor disagree (3)
- O Somewhat disagree (2)
- O Strongly disagree (1)

Q4.11 Additional Comments for Q4.10

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Q4.12 Laboratory equipment was modified so that you could complete a laboratory task

- O Yes (1)
- O No (2)
- O No Modifications were needed (6)

Q4.13 Additional Comments for Q4.12

Q4.14 The following were helpful to operating the laboratory equipment. Select 'Not Applicable' if the situation did not apply or the feature did not exist.

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)	Not Applicable (6)
Tool to help reach equipment (e.g. modified reacher) (Q4.14_1)	O	O	O	O	O	O
Computer simulations (Q4.14_2)	O	O	O	O	O	O
Operating equipment remotely (Q4.14_3)	O	O	O	O	O	O
Power wheelchair with seat elevation (Q4.14_4)	O	O	O	O	O	O
Camera system (Q4.14_5)	O	O	O	O	O	O
Mirrors (Q4.14_6)	O	O	O	O	O	O
Dials (Q4.14_7)	O	O	O	O	O	O
Buttons (Q4.14_8)	O	O	O	O	O	O
Single Action Levers (Q4.14_9)	O	O	O	O	O	O
Knobs (Q4.14_10)	O	O	O	O	O	O
Other (Q4.14_11)	O	O	O	O	O	O

Q4.15 Additional Comments for Q4.14

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Q4.16 The following are true statements about the laboratory equipment. Select 'Not Applicable' if the situation does not apply.

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)	Not Applicable (6)
Controls are reachable from seated position (Q4.16_1)	O	O	O	O	O	O
Easy to operate control knobs (Q4.16_2)	O	O	O	O	O	O
Hand controls of equipment operable without tight grasping, pinching, or twisting of the wrist (Q4.16_3)	O	O	O	O	O	O
Equipment operable without large force (Q4.16_4)	O	O	O	O	O	O
Assistive technology helped me complete laboratory tasks (e.g. reacher system, all-in-one auditory science laboratory tool, accessible microscope, other) (Q4.16_5)	O	O	O	O	O	O

Q4.17 Additional Comments for Q4.16

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Q4.18 Please list any assistive technology that helped you to complete laboratory tasks.

____

Q4.19 You were able to **independently** use **all** tools and other laboratory materials.

- O Yes (1)
- O No (2)

Q4.20 Additional Comments for Q4.19

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Q4.21 Please rate how much you agree with the statements in handling laboratory tools and equipment.

	Strongly agree (5)	Somewhat agree (4)	Neither agree nor disagree (3)	Somewhat disagree (2)	Strongly disagree (1)	Not Applicable (6)
Had difficulty independently gripping/clasping tools (1)	O	O	O	O	O	O
Had difficulty independently handling slippery material (2)	O	O	O	O	O	O

Q4.22 Additional Comments for Q4.21

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End of Block: Task Execution

APPENDIX B

SURVEY CONSENT FORM

Barriers and Facilitators to STEM Accessibility

The goal of this research study is to better understand, through the experiences of individuals with physical disabilities, both the type and the extent of the difficulties faced and existing accommodations encountered in Science, Technology, Engineering, and Mathematics (STEM) laboratories in college and university settings.

STEM laboratories typically include workbenches or other surfaces and machinery, equipment, and tools used to help analyze or solve science or engineering problems. We are interested in your experiences working in such lab spaces at community colleges, 2-year technical colleges, 4-year colleges and universities.

For this study, we are defining physical impairments as any severe difficulty using upper or lower limbs (e.g. difficulty grasping, reaching or standing). Full participation refers to being able to physically manipulate tools and equipment to complete a task. NOTE: If you acquired an impairment while in school, answer questions based on your experience post impairment.

This study is only for those over 18 years of age who had a physical impairment (permanent or temporary) while participating in a STEM laboratory setting. If you agree to participate you will complete an online questionnaire asking about your experiences while using a STEM laboratory. If you agree to complete a follow-up questionnaire we will email you a link approximately two-weeks after completing this online questionnaire. This follow-up will help to test the reliability of the survey. The questionnaire will take approximately 20 minutes to complete.

You will not directly benefit from participating in this research, however, the information you provide may help educate instructors and institutions on the identified barriers to accessibility and the steps they can take to accommodate students with physical disabilities. The information you provide will be reported only in aggregate form and your name will not appear anywhere. All information will remain confidential and will not be used for any purposes other than this study. Email addresses will be requested for survey follow-up. The email addresses provided will remain strictly confidential and will not be used for any purposes other than this study.

If you have any questions or need clarification about this study feel free to ask questions at any time. If you feel uncomfortable or have concerns about this questionnaire for any reason, you are free to discuss them with the principal investigator, Hervens Jeannis (hej7@pitt.edu) at any time. You may refuse to participate in this survey at any time without jeopardy. If the results of this study are published, any information provided will remain strictly confidential, and your privacy will not be compromised. Any statements shared will not be linked to your identity. Your research data may be shared with investigators conducting similar research, however, this information will be shared in a de-identified manner (without identifiers).

To thank individuals for participating in this research study, participant will be entered into a random chance to being chosen to receive (one of at least 10, $25 awards). Those who complete the re-test will be entered into a separate random chance to being chosen to receive to receive (one of at least ten, $35 awards). Awardees will be chosen at random at the end of data collection.

Responding to this questionnaire means you agree to have the data you provide included in this study. By clicking the button below, you acknowledge that your participation in the study is voluntary and that you are at least 18 years of age.

Please note that this questionnaire will be best displayed on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

B.1 IRB APPROVAL

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Ground Level
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)
http://www.irb.pitt.edu

<u>Memorandum</u>

To: Hervens Jeannis

From: IRB Office

Date: 7/17/2017

IRB#: MOD17020490-05 / PRO17020490

Subject: Barriers and Facilitators to STEM Accessibility Survey

---

The University of Pittsburgh Institutional Review Board reviewed and approved the requested modifications by expedited review procedure authorized under 45 CFR 46.110 and 21 CFR 56.110.

The IRB has approved the advertisement that was submitted for review as written. As a reminder, any changes to the advertisement other than to edit contact information requires IRB approval prior to distribution.

Modification Approval Date: 7/17/2017
Expiration Date: 4/4/2018

For studies being conducted in UPMC facilities, no clinical activities that are impacted by the modifications can be undertaken by investigators until they have received approval from the UPMC Fiscal Review Office.

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. Refer to the IRB Policy and Procedure Manual regarding the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least one month prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.

APPENDIX C

WIRE DIAGRAMS WITH SURVEY RESULTS

BE 1

Entering and exiting buildings with physical laboratory spaces

BUILT ENVIRONMENT

Physical or informational (e.g. entrance signage) barriers to reaching the building's main entrance (Q3.2)

n=101
N 75.2%
Y 24.8%

Physical barriers to the entrance of the main building (Q3.4)

n=101
N 76.2%
Y 23.8%

Physical barriers to the entrance of the science or engineering laboratory (Q3.6)

n=101
N 75.2%
Y 24.8%

N

Easy when entering the laboratory space (Facilitators) (n=76) (Q3.8)

- Operating Doors
  - **A(64.5%) | DA(26.3%) | Neither(9.2%) | N/A(7.9%)**
- Operating Elevators
  - **A(67.1%) | DA(9.2%) | Neither(13.2%) | N/A(10.5%)**
- Operating Platform Lifts
  - **A(9.2%) | DA(5.2%) | Neither(17.1%) | N/A(68.4%)**
- Ramps/Curb Cuts
  - **A(42.1%) | DA(9.2%) | Neither(14.5%) | N/A(25.7%)**
- Identifying Signs to Accessible Entrance
  - **A(39.5%) | DA(22.3%) | Neither(13.2%) | N/A(25%)**
- Other
  - **DA(4.9%) | Neither(14.8%) | N/A(80.3%) | N=61**

Y

Barriers to entering the laboratory space (n=25) (Q3.10)

- Width of Doors
  - **A(40%) | DA(24%) | Neither(12%) | N/A(24%)**
- Operating Doors
  - **A(52%) | DA(24%) | Neither (12%) | N/A(12%)**
- Operating Platform Lifts/Elevators
  - **A(52%) | DA(12%) | Neither (16%) | N/A(20%)**
- Curb Heights
  - **A(36%) | DA(20%) | Neither (20%) | N/A(24%)**
- Having Stairs or Steps
  - **A(52%) | DA(16%) | Neither (4%) | N/A(28%)**
- Other
  - **A(22.7%) | DA(4.5%) | Neither (18.2%) | N/A (54.5%) N=22**

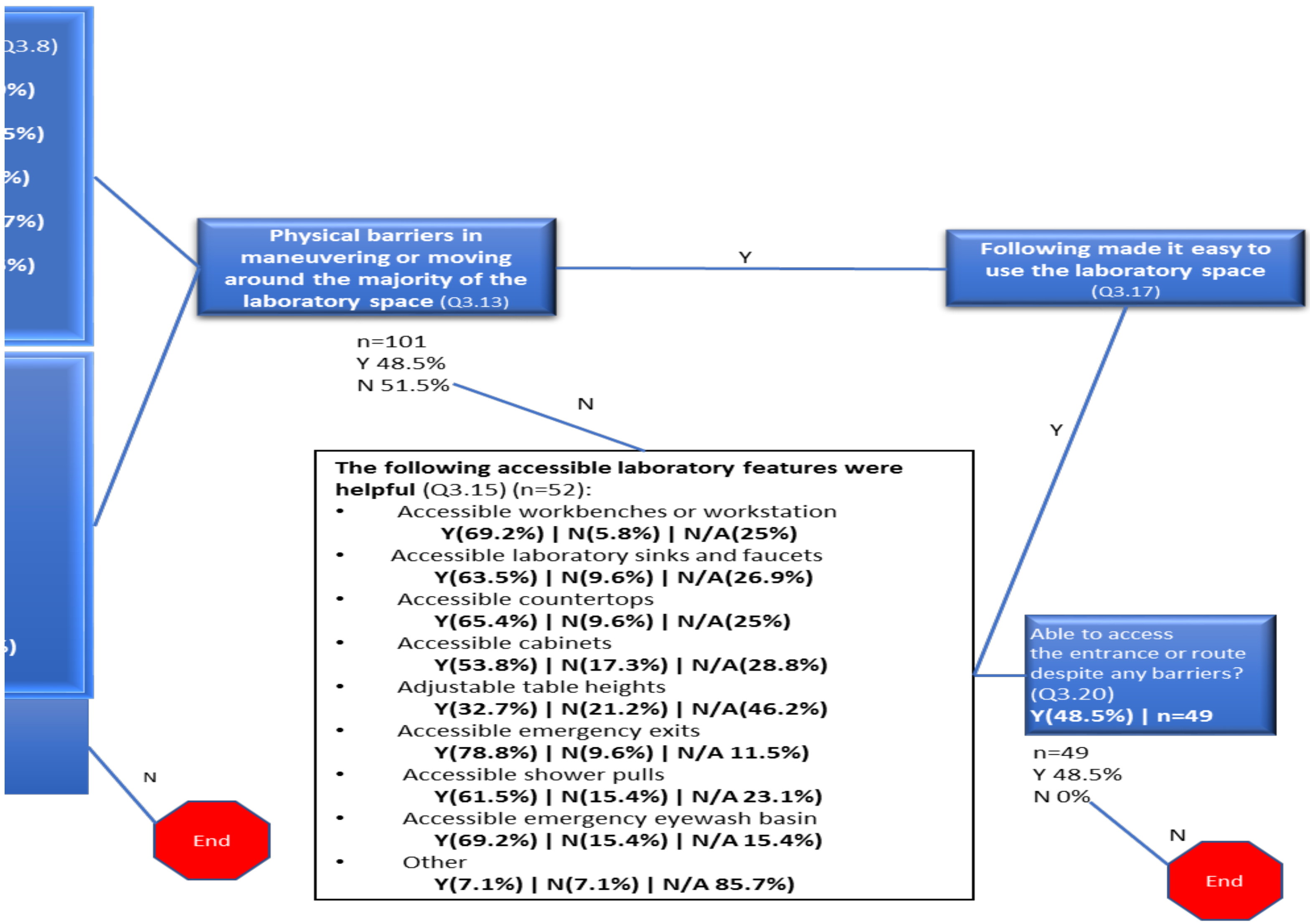
Able to access the entrance or route despite any barriers? (Q3.12)
Y(24.8%) | n=25

N

LEGEND

A= Strongly/somewhat agree
DA= Strongly/somewhat disagree
Neither = Neither agree or disagree
N/A = not applicable or not present
Y= Yes
N=No
n=number of respondents

Gaining access to facilities inside buildings



BE 2

Gaining access to facilities inside buildings

Q3.17

Following made it easy to use the laboratory space (n=101) (Q3.17)

- Aisles cleared
    - **A(50.5%) | DA(25.8%) | Neither(7.9%) | N/A (15.8%)**
- Accessible drawers and countertops
    - **A(47.5%) | DA(22.2%) | Neither(11.1%) | N/A (19.2%) | n=99**
- Height-adjustable tables
    - **A(15.8%) | DA(44.6%) | Neither(6.9%) | N/A (32.7%)**
- Raised platforms
    - **A(17.8%) | DA(30.7%) | Neither(11.9%) | N/A (39.6%)**
- Lowered shelves
    - **A(26.7%) | DA(24.7%) | Neither(15.8%) | N/A (32.7%)**
- Ramps
    - **A(24.8%) | DA(12.9%) | Neither(15.8%) | N/A (46.5%)**
- Accessible sinks/faucets
    - **A(37.6%) | DA(22.8%) | Neither(11.9%) | N/A (27.7%)**
- Power strips placed within reach of user
    - **A(36.6%) | DA(24.7%) | Neither(12.9%) | N/A (25.7%)**
- Other
    - **A(2.6%) | DA(3.8%) | Neither(14.1%) | N/A (79.5%) | n=78**

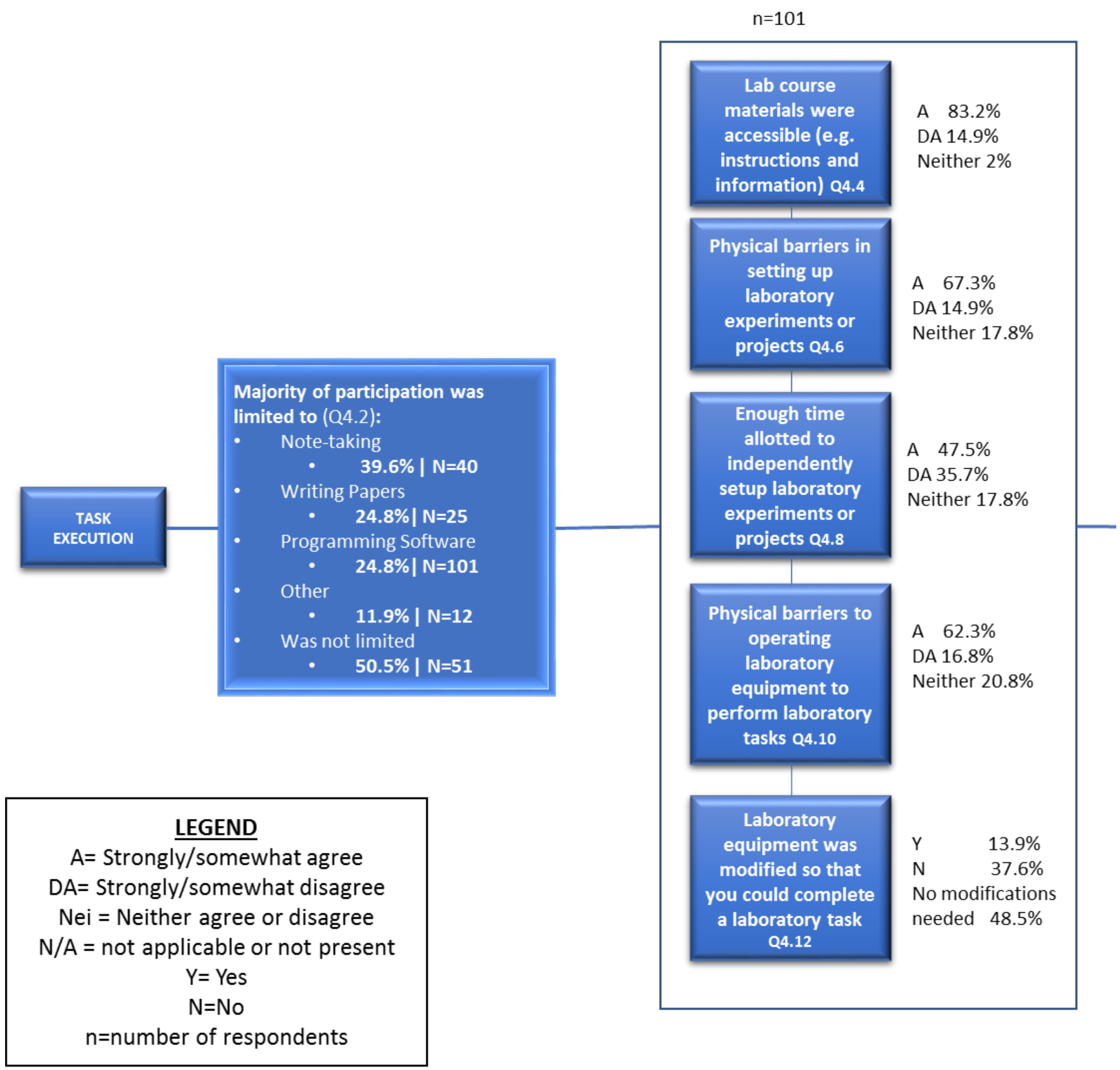
Safety procedures were addressed: (n=101) (Q3.23)

- Accessible Emergency Exits
    - **A(60.4%) | DA(17.8%) | Neither(6.9%) | N/A(14.9%)**
- Accessible shower pulls
    - **A(51%) | DA(12%) | Neither (12%) | N/A(25%)**
- Accessible emergency eyewash basin
    - **A(57.4%) | DA(13.9%) | Neither (7.9%) | N/A(20.8%)**
- Safety measures for handling HAZMAT
    - **A(49.5%) | DA(23.8%) | Neither (2.9%) | N/A(14.9%)**
- Alt. arrangements for emergencies
    - **A(48.5%) | DA(22.7%) | Neither (5.9%) | N/A(22.8%)**
- Other
    - **A(7.4%) | DA(8.6%) | Neither (8.6%) | N/A(75.3%) | N=81**

LEGEND

A= Strongly/somewhat agree
DA= Strongly/somewhat disagree
Neither = Neither agree or disagree
N/A = not applicable or not present
Y= Yes
N=No
n=number of respondents

TE 1 Laboratory Setup Ope



Operating Lab Equipment

Helpful to operating the laboratory equipment (n=101) Q4.14

- Tool to help reach equipment (e.g. modified reacher)
    - **A(16.8%) | DA(8.9%) | Neither(5%) | N/A(69.3%)**
- Computer simulations
    - **A(19%) | DA(9%) | Neither (9%) | N/A(63%) | N=100**
- Operating equipment remotely
    - **A(14.9%) | DA(5.9%) | Neither (9.9%) | N/A(69.3%)**
- Power wheelchair with seat elevation
    - **A(9%) | DA(7%) | Neither (7%) | N/A(77%) | N=100**
- Camera system
    - **A(12.9%) | DA(6%) | Neither (5%) | N/A(76.2%)**
- Mirrors
    - **A(10%) | DA(9%) | Neither (7%) | N/A(74%) | N=100**
- **Dials**
    - **A(14.9%) | DA(10.9%) | Neither (10.9%) | N/A(63.4%)**
- **Buttons**
    - **A(22.2%) | DA(11.2%) | Neither (11.1%) | N/A(55.6%) |N=99**
- **Single Action Levers**
    - **A(13%) | DA(12%) | Neither (8%) | N/A(68%) | N=100**
- **Knobs**
    - **A(18.8%) | DA(15.8%) | Neither (9.9%) | N/A(55.4%)**
- **Other**
    - **A(2.3%) | DA(1.2%) | Neither (3.5%) | N/A(93%) | N=86**

Q4.16

True statements about the laboratory equipment (n=100) Q4.16

- Controls are reachable from seated position
    - **A(31%) | DA(40%) | Neither(6%) | N/A(23%)**
- Easy to operate control knobs
    - **A(43%) | DA(24%) | Neither (10%) | N/A(23%)**
- Hand controls of equipment operable without tight grasping...
    - **A(26%) | DA(43%) | Neither (10%) | N/A(21%)**
- Equipment operable without large force
    - **A(38%) | DA(31%) | Neither (10%) | N/A(21%)**
- Assistive technology helped me complete laboratory tasks
    - **A(15%) | DA(18%) | Neither (7%) | N/A(60%)**

LE

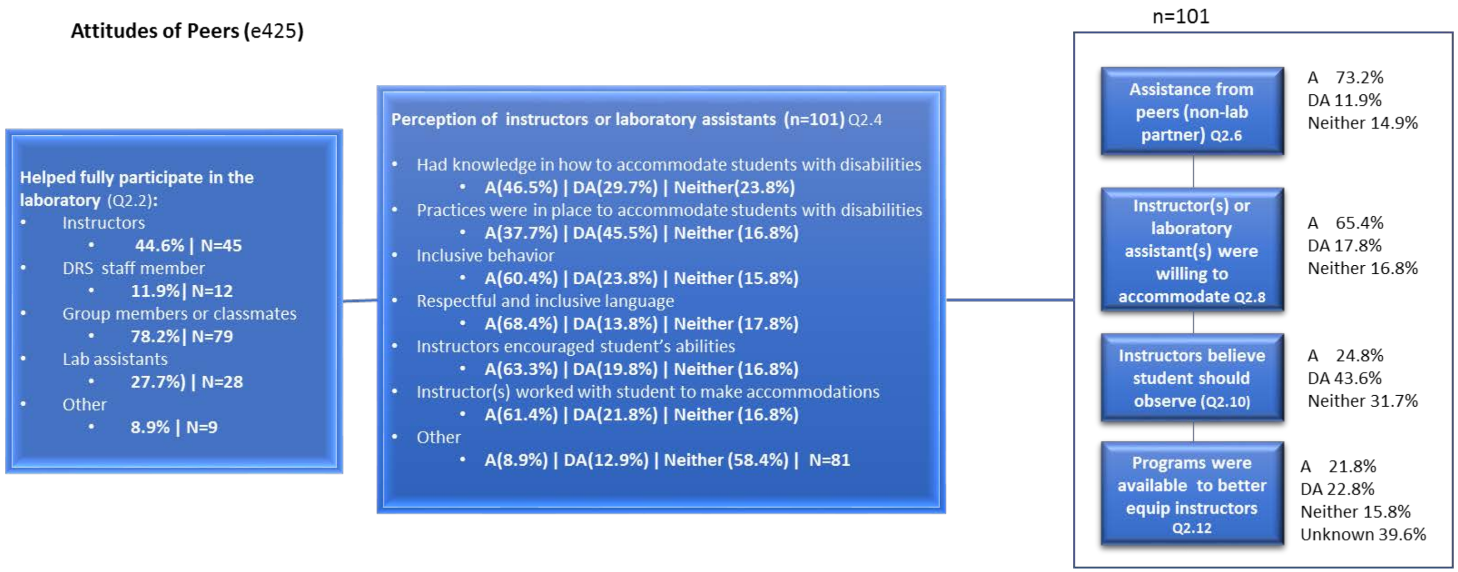
Training Programs for STEM Laboratory Instructors to Help SwD (e5850)

Attitudes of Peers (e425)

Attitudes of People in Authority (e430)

Attitudes of people in authority (e430)

Attitudes of Peers (e425)



APPENDIX D

CODEBOOK DEVELOPMENT WITH ICF DEFINITIONS

Data Bounded by The International Classification Framework:

Barriers and Facilitators Categories	**ICF Terminology (ref#)**
<u>Learning</u>	
Instructors Strategies for instructors	• People in positions of authority (e330, e360)
Programs and initiatives to help instructors	• Attitudes of people in authority (e430)
Peers	• People in subordinate positions, peers and colleagues and personal attendants (e325,e335, e340) • Attitudes of peers (e425, e435)
Laboratory Courses	• Education and training services (e5850)
<u>Facilities</u>	
Access to Facilities	• Design, construction and building products and technology for public use (e150) • Entering and exiting buildings (e1500)

Safety	• Gaining access to facilities inside buildings (e1501) • Architecture and construction policies: fire and life standards (e5152)
<u>Equipment</u> Alternative known methods Workspace modifications Adaptations and AT Simple equipment modifications	• General products for education (e1300) and communication (e1250) • Assistive products and technology for education (e1301) and communication (e1251) Products and technology for personal indoor mobility (e120)
<u>Preparation for future in STEM Careers</u> Student Preparation Mentorship Self-advocacy	• Education and training services (e5850) • Informal social relationships (d750) • Basic social and interaction skills (d710)

Gen Code:	**Entering and Exiting buildings**
Specific Code (ICF):	Design, construction and building products and technology for entering and exiting buildings for public use (e1500) <- e150 Design, construction and building products and technology of buildings for public use
Brief Definition	Entering and exiting a public building that has laboratory within its property
Full Definition (ICF)	"Products and technology of entry and exit from the human-made environment that is planned, designed and constructed for public use, such as design, building and construction of entries and exits to buildings for public use (e.g. workplaces, shops and theatres), public buildings, portable and stationary ramps, power-assisted doors, lever door handles and level door thresholds."

When to use	When information is related to entering and exiting the physical building in which the laboratory is located
When not to use	When information is not about building in which the laboratory is located; laboratory equipment is discussed
Example:	N/A

Gen Code:	**Entering and existing laboratory spaces**
Specific Code:	Design, construction and building products and technology for gaining access to facilities inside buildings for public use (e1501) <- e150 Design, construction and building products and technology of buildings for public use
Brief Definition	Accessing physical laboratory space within a building
Full Definition	"Products and technology of indoor facilities in design, building and construction for public use, such as washroom facilities, telephones, audio loops, lifts or elevators, escalators, thermostats (for temperature regulation) and dispersed accessible seating in auditoriums or stadiums."
When to use	Information is about entering laboratory space
When not to use	not about the physical building in which the laboratory is located
Example:	N/A

Gen Code:	**Alternative known methods OR** **Non-adapted technology and equipment**
Specific Code:	General products and technology for education (e1300) <- e130 Products and technology for education e1250 General products and technology for communication
Brief Definition	Non-adapted technology and equipment
Full Definition	E1300 "Equipment, products, processes, methods and technology used for acquisition of knowledge, expertise or skill at any level, such as books, manuals, educational toys, computer hardware or software, not adapted or specially designed" E1250 "Equipment, products and technologies used by people in activities of sending and receiving information, such as optical and auditory devices, audio recorders and receivers, television and video equipment, telephone devices, sound transmission systems and face-to-face communication devices, not adapted or specially designed."
When to use	When an off-the-shelf product is discussed, this may include AT products; moving already-established equipment as a modification is mentioned
When not to use	When new technology is adapted or developed

Example:	'video cameras'; moving powerstrips closer to the user

Gen Code:	**Adapted technology and equipment OR prototypes in development**
Specific Code:	e1301 Assistive products and technology for education <- e130 AT products for education e1251 Assistive products and technology for communication
Brief Definition	Adapted equipment (e.g.AT) and methods used for education or communication
Full Definition	E1301 "Adapted and specially designed equipment, products, processes, methods and technology used for acquisition of knowledge, expertise or skill, such as specialized computer technology"... "for improving the functioning of person with a disability" E1251 " Adapted or specially designed equipment, products and technologies that assist people to send and receive information, such as specialized vision devices, electro-optical devices, specialized writing devices, drawing or handwriting devices, signalling systems and special computer software and hardware, cochlear implants, hearing aids, FM auditory trainers, voice prostheses, communication boards, glasses and contact lenses."
When to use	When new technology (e.g. AT) is prototyped or developed for a specific activity in the laboratory; when technologies are modified and adapted or when computer simulations are discussed;
When not to use	When off-the-shelf product standard product is used (e.g. video-camera);
Example:	All in one scientific tool (12 vernier sensors); automated robotic tools, attaching a "spoked" knob to the original knob for microscope dials

Gen Code:	**AT products for transportation**
Specific Code:	e1201 Assistive products and technology for personal indoor and outdoor mobility and transportation
Brief Definition	AT products used for transportation
Full Definition	"Adapted or specially designed equipment, products and technologies that assist people to move inside and outside buildings, such as walking devices, special cars and vans, adaptations to vehicles, wheelchairs, scooters and transfer devices."
When to use	AT mobility devices
When not to use	non-AT mobility devices are mentioned
Example:	'Wheelchairs and scooters'

SUPPORTS AND RELATIONSHIPS (3)

Gen Code:	**Student peers**

Specific Code:	e325 Acquaintances, peers, colleagues, neighbours and community members & e335 People in subordinate positions
Brief Definition	Student peers in STEM laboratory course
Full Definition	E325 "Individuals who are familiar to each other as acquaintances, peers, colleagues, neighbours, and community members, in situations of work, school, recreation, or other aspects of life, and who share demographic features such as age, gender, religious creed or ethnicity or pursue common interests." E335 "Individuals whose day-to-day life is influenced by people in positions of authority in work, school or other settings, such as students, workers and members of a religious group"
When to use	When student peers are mentioned; assistance from other students is mentioned
When not to use	When personal attendants are mentioned
Example:	N/A

Gen Code:	**Personal assistants**
Specific Code:	e340 Personal care providers and personal assistants
Brief Definition	Those who are hired to help students with disabilities
Full Definition	"Individuals who provide services as required to support individuals in their daily activities and maintenance of performance at work, education or other life situation, provided either through public or private funds, or else on a voluntary basis, such as providers of support for home-making and maintenance, personal assistants, transport assistants, paid help, nannies and others who function as primary caregivers."
When to use	When personal attendants are mentioned; assistance from personal attendants is mentioned
When not to use	*immediate family (**e310**); extended family (**e315**); friends (**e320**); general social support services (e5750); health professionals (**e355**)*
Example:	N/A

Gen Code:	**Positions of authority**
Specific Code:	**e330 People in positions of authority** **e360 Other professionals**
Brief Definition	Instructors who are teaching the STEM course instructors/staff not in direct authority over students
Full Definition	e330"Individuals who have decision-making responsibilities for others and who have socially defined influence or power based on their social, economic, cultural or religious roles in society, such as teachers, employers, supervisors, religious leaders, substitute decision-makers, guardians or trustees."

	e360"All service providers working outside the health system, including lawyers, social workers, teachers, architects and designers."
When to use	When instructors or laboratory assistants are mentioned; assistance from instructors, staff or hired laboratory assistants are mentioned
When not to use	*health professionals (e355); when students peers are mentioned*
Example:	N/A

ATTITUDES (4)

Gen Code:	**Attitudes of peers**
Specific Code:	e425 Individual attitudes of acquaintances, peers, colleagues, neighbours and community members & e435 Individual attitudes of people in subordinate positions
Brief Definition	Attitudes, opinions and beliefs of the students with disabilities from student peers
Full Definition	E425 "General or specific opinions and beliefs of acquaintances, peers, colleagues, neighbours and community members about the person or about other matters (e.g. social, political and economic issues), that influence individual behaviour and actions." E435"General or specific opinions and beliefs of people in subordinate positions about the person or about other matters (e.g. social, political and economic issues), that influence individual behaviour and actions"
When to use	When attitudes or opinions of students are mentioned
When not to use	Attitudes of laboratory assistants or instructors are mentioned
Example:	N/A

Gen Code:`	**Attitudes of instructors**
Specific Code:	e430 Individual attitudes of people in positions of authority
Brief Definition	Attitudes, opinions and beliefs of the students with disabilities from instructors, staff and laboratory assistants
Full Definition	"General or specific opinions and beliefs of people in positions of authority about the person or about other matters (e.g. social, political and economic issues), that influence individual behaviour and actions."
When to use	When attitudes of staff or instructors are mentioned
When not to use	When attitudes of student peers are mentioned
Example:	N/A

SVCS, SYSTEMS & POLICIES (5)

Gen Code:	**Training programs**
Specific Code:	e5850 Education and training services
Brief Definition	Training programs and services provided for institutions and STEM laboratories
Full Definition	"Services and programmes concerned with education and the acquisition, maintenance and improvement of knowledge, expertise and vocational or artistic skills, such as those provided for different levels of education (e.g. preschool, primary school, secondary school, post-secondary institutions, professional programmes, training and skills programmes, apprenticeships and continuing education), including those who provide these services."
When to use	When training programs and services provided for institutions and STEM laboratories to help SwD or STEM instructors better prepared to teach SwD; mentorship opportunities; strategies, programs and initiatives to help instructors teach SwD;
When not to use	When administrative components and logistics of the programs are mentioned
Example:	N/A

Gen Code:	**Administrative components**
Specific Code:	"e5851 Education and training systems"
Brief Definition	Administrative and logistical components of programs or strategies
Full Definition	"Administrative control and monitoring mechanisms that govern the delivery of education programmes, such as systems for the implementation of policies and standards that determine eligibility for public or private education and special needs-based programmes; local, regional or national boards of education or other authoritative bodies that govern features of the education systems, including curricula, size of classes, numbers of schools in a region, fees and subsidies, special meal programmes and after-school care services."
When to use	When administrative components and logistics of the programs are mentioned
When not to use	When the specific types of programs available are listed
Example:	N/A

Gen Code:	**Mentorship**
Specific Code:	d750 Informal social relationships
Brief Definition	Relationships with others
Full Definition	"Entering into relationships with others, such as casual relationships with people living in the same community or residence, or with co-workers, students, playmates or people with similar backgrounds or professions."

to use	"Inclusions: informal relationships with friends, neighbours, acquaintances, co-inhabitants and peers"
When not to use	N/A
Example:	N/A

Gen Code:	**Self-advocate**
Specific Code:	d710 Basic interpersonal interactions
Brief Definition	Advocating for self, starting relationships with others
Full Definition	"Entering into relationships with others, such as casual relationships with people living in the same community or residence, or with co-workers, students, playmates or people with similar backgrounds or professions."
When to use	Inclusions: "showing respect, warmth, appreciation, and tolerance in relationships; responding to criticism and social cues in relationships; and using appropriate physical contact in relationships"
When not to use	N/A
Example:	N/A

APPENDIX E

LOGIC DIAGRAM

Logic Model for Accessible S&E Laboratories Exploration

Need Assessment

Identify SwD-P perceived barriers:

- 92% of S&E jobs will require post-secondary education/ training

(Carnevale et al., 2010)

- Only 7.2% of the S&E workforce is comprised of PwD with at least a bachelor's degree

(NSF, 2015)

- Lack of understanding in accommodating SwD-P

(Pivik et al., 2002)

Identify Facilitators:

- Increasing presence of inclusive programs

ABIL (Duerstock et al., 2013) DO-IT (Burgstahler & Chang, 2014) ELaVATE (Goldberg et al., 2015)

Assumptions

- Given proper support SwD-P can fully participate in S&E (Supalo et al., 2014)
- Hands-on training at postsecondary level helps obtain education needed to obtain S&E jobs

(Carnevale et al., 2010)
(Cooper, 1995)

Inputs Activities

- **Write literature review manuscript** on barriers and facilitators to S&E laboratories for SwD-P from literature
- **Identify barriers** in instructional S&E laboratories
- **Identify facilitators** (existing accommodations, examining strategies that orgs and instructors can use to accommodate SwD-P)
- **Initiate survey psychometrics**
- Complete survey translational validity
- Check survey for stability of responses

Outputs (Effects)

- Prevalence and severity of barrie identified and reported
- Prevalence and complexity of facilitators identified and reported

Outcomes (Ultimate Impact)

- Educate institutions and instructors on barriers and steps they can take to help accommodate SwD-P to obtain hands-on training in instructional S&E laboratories.
- Documentation with empirical data of barriers and facilitators in postsecondary S&E instructional laboratory environment that instructors can reference

EVALUATION:
Data: Surveys (SwD-P)

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