Physically-Disabled Students in Summer Undergraduate Research Environments

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***Abstract*—*Contribution:* This study uncovered *specific* benefits, challenges, and facilitators to participating in undergraduate research for physically-disabled students (PDS) taken directly from students themselves. *Background:* Disabled students (DS) earn bachelor's degrees and gain employment in STEM careers at rates lower than their peers. The paradigm shift in undergraduate STEM education from lecture-based to inquiry-based learning is an opportunity to explore new options for including disabled students. Little is known about designing inquiry-based learning settings for disabled students. *Research question:* This paper seeks to increase understanding of how to support physically-disabled students in inquiry-based settings. Specifically, the authors documented the experiences of PDS in a summer undergraduate research program to uncover 1) benefits they receive from participating, 2) specific challenges these students face, and 3) novel ways to facilitate participation. *Methodology:* The authors conducted semi-structured interviews of five undergraduate PDS who participated in a summer research program. The paper reports representative student responses across themes related to benefits, challenges and facilitators of success in the program. *Findings:* The students enjoyed many benefits typically gained from undergraduate research, most notably career clarification. Additionally, the students experienced personal growth including improved self-advocacy, increased confidence in their independence, and greater understanding of limitations. The main facilitator was the positive attitudes of research mentors. A principal challenge was lack of knowledge about disability in peers without disabilities who participated in the program.**

***Index Terms*—students with disabilities, disabled students, undergraduate research, diversity and inclusion, barriers to participation, facilitators of participation, biomedical engineering.**

I. Introduction

WHILE disabled students enrolled in undergraduate programs choose Science, Technology, Engineering, and Math (STEM) majors in proportions similar to their peers, they are underrepresented in terms of degree attainment and subsequent employment in STEM careers. 20% of U.S. undergraduate DS majored in computer or information science, life sciences, physical sciences, mathematics, or engineering [1]. This is only slightly less than the 21% of their peers without disabilities enrolled in the same majors [1]. 19% of U.S. undergraduate students majoring in STEM have a disability [1]. However, only 7% of recent science and engineering graduates (age 29 and under) have a disability [2]. 43% of DS vs. 30% of their peers drop out without a degree after six years [3]. Although definitions of disability vary, using the definition from the National Survey of College Graduates [2], this paper defines disabled students (DS) as those having at least moderate difficulty 1) seeing with eye glasses, 2) hearing with a hearing aid, 3) walking without assistance, or 4) concentrating, remembering, or making decisions. Physically-disabled students (PDS) are those with moderate difficulty with at least one of the first three activities. These data suggest DS face significant challenges in attaining STEM degrees. However, the authors are unaware of definitive evidence to explain these degree attainment and career participation gaps.

Anecdotal evidence, primarily from educators, begins to explain this gap. Explanations include negative attitudes of instructors and peers towards disabled students [4], lack of preparation due to exclusion from advanced STEM courses in high school [5], scarcity of mentors with disabilities [6], lack of education and resources for faculty desiring to implement accessible pedagogy [7], and individualistic faculty culture preventing broad implementation of universal design for learning practices [7]. A long list of specific physical barriers have been chronicled in recent review articles [7], [8].

Further complicating matters is the transformation from lecture-based to inquiry-based undergraduate STEM instruction. The Boyer Report [9] recommends making research central to the undergraduate experience and inquiry-based experiences throughout STEM degree programs. While these open-ended environments likely improve career readiness, they present additional challenges for physically-disabled students. For example, the accessibility of off-campus locations for fieldwork [10] or internships [7] is more uncertain. Inquiry-based learning often requires students rather than the instructor to define tasks, so identifying accommodations is more difficult [7]. Team dynamics is another challenge as PDS are assigned roles (e.g. taking notes) that limit their experiences [11] and unpredictable demands are placed on PDS [7].

General principles guide efforts to make undergraduate and graduate STEM education more inclusive. Universal Design for Learning (UDL) attempts to change the educational environment by using multiple means of representation, expression, and action rather than offer specific accommodations [12]. Empirical literature is too sparse to indicate the success of UDL in post-secondary environments and especially sparse in STEM [13]. Meeks et al. wrote a guide on including DS in medical education [14] suggesting there are significant structural and cultural barriers present [15].

However, little is known about specific challenges and avenues to participation of PDS in inquiry-based environments such as research settings [8]. To empower PDS to earn degrees and participate fully in the workforce there is a clear need to identify barriers and facilitators of full participation. A recent

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This work is supported by NSF Grant 1659559.

review paper [8] suggests the way forward to yield actionable policies is to capture the specific experiences of students rather than the general impressions of educators.

The authors aim to create accessible research experiences for physically-disabled students. Undergraduate research has well-documented benefits for students in general [16], [17] and especially for students from underrepresented minority groups [18], [19]. Benefits include the ability to take project ownership, learning professional habits, increased confidence, relationships with peers and mentors, career clarification, and graduate school preparation. Summer research experiences encapsulate much of the unexplored landscape for DS [7] – team environments, open-ended inquiry, field work, and participation in the research community. Students' experiences in summer research can inform efforts in universal design for learning as STEM education continues to move from lecture-based to experiential learning models.

This study documents experiences of physically-disabled students in undergraduate research to improve understanding of 1) benefits, 2) challenges, and 3) novel ways to facilitate participation. The authors interviewed five PDS who participated in a ten-week summer research experience. A previous case series profiled the program's impact on three of the five students [20].

II. Methods

This is a qualitative study where the researchers seek to understand 1) benefits physically-disabled students received from participating in a summer research program, 2) specific challenges they faced, and 3) novel ways to facilitate greater participation of PDS. The goal was to document the experiences of five undergraduate PDS described in Table I in a research experiences for undergraduates (REU) program away from their home university. The students described gave consent to participate, and data was collected in accordance with Cleveland State University institutional review board protocol IRB-FY2017-169.

A. Summer research program description

Three cohorts of students from universities around the U.S. participated in a 10-week REU program during the summers of 2017, 2018, and 2019. There were 10-12 students in each cohort. The broad research topic of the program was rehabilitation engineering. The objectives of the program were to 1) immerse undergraduate engineering students in the challenges of developing technology for physically-disabled persons. 2) motivate students to pursue opportunities in rehabilitation and assistive technology, and 3) empower students to succeed in careers in rehabilitation and assistive technology.

To achieve these objectives, the program recruited diverse cohorts across class standing, major, gender, disability status, and ethic/racial category. The main program elements were 1) full-time participation on a mentored research project; 2) living with other program students in dormitory apartments; 3) a weekly professional development seminar; 4) regular contact with disabled persons and health care providers either through the research projects themselves or via optional field trips to hospitals and assistive equipment providers and manufacturers; 5) presenting their research to high school students and via a poster at a national academic conference.

The faculty co-directors designed and oversaw program execution. One was a mechanical engineer who interacts regularly with people with spinal cord injuries as a part of his research program. The other was a physical therapist with a clinical background working with disabled persons. They selected each cohort, assigned students to their respective labs, and served as research advisors. They assisted with the students' arrival and orientation, designed and participated in the seminars and outside activities, attended conferences with students, and worked with the Office of Disability Services to provide accommodations as needed.

The program was designed to offer support responsive to students' daily needs. Each student worked on a research project supervised by one of seven faculty advisors who met with the student at least once a week, but generally more often. Most students also met daily with a graduate student mentor in their lab group. Some students worked in pairs on projects, and all students worked in laboratories where other undergraduate and graduate students were present and available for research and social support. The faculty advisors were all invested in undergraduate research and supporting PDS, but did not receive any specific training in these areas.

The program offered additional support to physically-disabled students. The students lived and worked in the dormitory, student center, and four academic buildings. Five buildings were built since 2000 and are compliant with the Americans with Disabilities Act. The physical therapist program co-director met each PDS upon their arrival to the dormitory to offer help with room setup and identify further modifications or assistive equipment. An assitive technology specialist walked through the student's work space with the student, her/his faculty advisor, and a program co-director to describe the student's duties and identify and implement any necessary modifications to the work environment. Students were paired with faculty advisors invested in working with PDS.

B. Description of student participants with disabilities

This paper highlights five physically-disabled students, who all participated fully in the program. The students are referred to with pseudonyms to protect their anonymity. See Table I for descriptions of their academic backgrounds and the nature of their disabilities. There were no physically-disabled students who participated in the program and were not interviewed.

a) Brad: Brad worked in industry and in the U.S. Marine Corps Reserves before entering college. He sustained a thoracic-level spinal cord injury several years prior to participating in the 2017 cohort. Brad has full use of his upper extremities and uses a wheelchair that he propels with his hands. This was his first independent stay away from home and first long-distance trip since his spinal cord injury; his wife came with him and helped setup him dorm room, flew home, and returned to drive back with him at the end of the ten weeks. Brad brought adaptive equipment to use in the dorm bathroom

TABLE I
SUMMARY OF STUDENTS' ACADEMIC AND DISABILITY BACKGROUNDS (PSEUDONYMS USED)

	Cohort	Major	Mentor's disability experience	Year	self-identified gender	Disability condition	Mobility aide	Other equipment from home	Local trans-portation	Caregiver required
Brad	2017	mechanical engineering	medium	senior	male	paraplegia	manual wheelchair	yes	adapted car	no
Erica	2018	biomedical engineering	low	junior	female	Arthrogryposis Multiplex Congenita	power wheelchair	yes	wheelchair van	yes
Mark	2018	computer science	medium	junior	male	Duchenne Muscular Dystrophy	power wheelchair	yes	wheelchair van	yes
Chris	2018	mechanical engineering	medium	junior	male	chronic joint pain, PTSD	cane	no	own car	no
Morgan	2019	biomedical engineering	high	junior	male	chronic pain and fatigue	forearm wheeled walker	no	none	no

which allowed Brad to be fully independent in his self-care and dorm life. He attended all program activities and accessed the campus and local area independently either by wheelchair or his adapted car. Brad could enter, exit, and work in his lab space independently without modification to the space.

Brad's faculty advisor was the program co-director who does research in spinal cord injury. Brad worked on a project with another student in the program and received close guidance from a graduate student. The lab group had one other graduate student, and two other undergraduate students who did not work closely with Brad. Another lab group including two graduate and two undergraduate students shared a common workspace with Brad's group. None of the other students have disabilities. Brad designed and built a sensor to be worn on the wrist by a person with a spinal cord injury. His daily activities included making models in a computer-aided design program, selecting, purchasing, and/or 3D printing components, and writing software to read his sensor. His activities were not restricted by his disability. Brad presented a poster at the International Symposium on Wearable and Rehabilitation Robotics in Houston. He drove to the conference and shared a rented apartment with a graduate student. Brad attended 10 of 10 weekly seminars and 3 of 9 optional activities.

b) Erica: Erica, who was born with a condition of joint contractures and missing muscles (Arthogryposis Multiplex Congenita), was enthusiastic to participate in the 2018 cohort but had concerns about housing and accessibility that prevented her from committing immediately. A program co-director assured Erica that her spot would be held for as long as she needed to feel comfortable about accommodations. She uses a power wheelchair and cannot open doors or do some self-care activities due to limited dexterity. Before arrival automatic door opening systems were installed to allow independent access to her dorm room.

This was Erica's first prolonged time away from home and the care of her family. Her mother arrived with her in her wheelchair adapted and returned home leaving the van in Cleveland. They brought a significant amount of adaptive equipment to make her bathroom and bedroom accessible. Erica's long-time paid caregiver lived in an adjoining room in her dorm suite and assisted Erica with dressing, mobility, exercise, and hygiene needs in the morning and evening. The program paid for the caregiver's dorm room. Erica attended all campus program activities without the help of her aide, as well as some local community activities accessible in her power wheelchair. Her wheelchair van, driven by the caregiver or a fellow student, allowed her to attend other off-campus social and program activities.

Erica attended all weekly seminars and nine of eleven elective off-campus experiences such as a trip to a prosthetics company and to a gym designed for people with spinal cord injuries. On a visit to a wheelchair dance company, Erica fell out of her wheelchair while trying a dance maneuver with members of the company and broke her knee-ankle-foot orthosis. The physical therapy co-director contacted a local orthotist who agreed to see Erica and repair the brace.

Erica's faculty mentor was a mechanical engineering professor who does not typically work with physically-disabled persons. She worked independently on a computer simulation of the knee, with close supervision of a graduate student. Erica completed her work satisfactorily despite her inability to type quickly. She was intentionally placed in this assignment rather than in a community garden project where wheelchair accessibility was limited. Her lab group included one other undergraduate and one graduate student who did not work closely with her. Erica's lab space was shared by a second lab group including three other undergraduate and two graduate students. None of the other students has a disability. Her lab lacked an automatic door, so program staff made sure that another person was always present to open doors for her. Otherwise she could navigate her workspace independently.

Erica attended the Biomedical Engineering Society (BMES) Annual Conference in Atlanta with other students in the program and the program co-director. Her mother drove her to the conference and attended with her. Erica found it difficult to find an accessible hotel room. She was hesitant to reserve a room because of the perceived high cost, but reserved the room after reassurance that the program would reimburse her.

She presented a poster at the conference, attended talks, and went out to dinner with a group of students in her cohort.

c) Chris: Chris served 11 years in the U.S. Army before college. He had chronic joint pain and post-traumatic stress disorder (PTSD). Despite being offered the opportunity, Chris chose not to speak with the Office of Disability Services. He did however request a dorm room on the first floor and a disabled parking space. Chris drove from his home to Cleveland rather than flying. Chris lived in the dormitory and participated in the program independently.

Program staff did not initially realize his PTSD included hypervigilance. He was uncomfortable in crowded rooms with multiple doors or windows and preferred to sit alone near the back of a room. He revealed this to program staff when he was noticeably anxious and uncomfortable at the first weekly seminar which met in a small ground floor room with multiple glass windows and two doorways. As a result, the program changed seminar rooms to accommodate his needs when possible, giving him the room and attendance information in advance and letting him decide to miss a seminar due to his hypervigilance. He decided to miss two of the seminars that were in crowded locations (out of ten seminars) and also left the crowded luncheon after the high school presentations. Chris was not always comfortable at the seminars he attended, commenting in his focus group interview, “the joint seminars are the ones I didn’t like, too crowded for me.”

Chris designed a prosthetic leg, making solid models in a computer aided design program, 3D printing and machining parts, and assembling a prototype. His work assignments were not affected by his disabilities. Chris worked with Mark, another physically-disabled student in the cohort (see below). His faculty mentor was an electrical engineering professor who works with people with amputations and other disabilities in his family and professional life. A doctoral student without a disability supervised Chris on a day-to-day basis.

Chris attended the BMES Annual Conference in Atlanta with other students in the program and a program co-director. He drove to the conference, presented a poster, attended talks, and had dinner with the group at the conference. He chose to participate in only two of the eleven off-campus events during the summer, fewer than many others in the cohort.

d) Mark: Mark has Duchenne Muscular Dystrophy which causes progressive weakening of muscles. Mark uses a power wheelchair and has limited manual dexterity. He was excited about participating in the 2018 cohort but had many questions before he eventually committed to participating. He asked if he was selected because of his disability. The program director assured Mark that all selected students, including him, had strong academic records and unique backgrounds. He was also concerned about the timing and amount of stipend he would receive and how that would affect his access to government disability benefits. Without imposing a deadline, the program assured Mark that his place would be reserved until all logistics of his participation could be sorted out.

Before his arrival Mark worked with the Office of Disability Services to facilitate his participation in the program. Automatic door opening systems were installed to allow hands-free access to all parts of his dorm room. Similar automatic doors were not installed in Mark’s lab. Instead, Mark’s faculty advisor made sure Mark was always with someone in the lab. Typically that was Chris (see above) with whom Mark worked closely. Some minor changes were made to the physical layout of the laboratory space to accommodate Mark’s wheelchair.

Mark arrived in his wheelchair access van with his parents who assisted him in setting up his dorm room. The co-director was available in the dorm but no additional help was required. The van remained on campus enabling Mark to attend off-campus events. Mark and his family hired a local caregiver for morning, afternoon, and evening assistance with dressing, eating, mobility, exercise, and hygiene needs. They also hired a local service to bring Mark’s meals except those provided at the program’s weekly seminar.

Early each afternoon Mark ate lunch and rested in his dorm room and returned to the laboratory later in the afternoon. He completed assigned work in the evening to make up lost time during the afternoon. Mark’s early afternoon and evening routines with his caregiver made it difficult for him to participate in some off-campus activities, informal lunches, dinners, or outings in Cleveland with the rest of the cohort. Mark attended all ten weekly seminars but only two of eleven optional program activities.

Mark worked together with Chris (see above) in the laboratory to design and build a prototype prosthetic leg. He worked under the direction of the same faculty mentor and graduate student as Chris. Mark wrote computer code to communicate with sensors and motors while Chris did mechanical design. Mark’s lab assignment was chosen primarily because he was a computer science major and partly because it did not rely on manual dexterity.

Mark briefly attended the BMES Annual Conference with other students in the program and the co-director. He planned to fly to Atlanta with his father on the day of his poster presentation and return home on the same day. Mark was not comfortable with staying overnight in a hotel. To accommodate air travel Mark needed to use a smaller wheelchair than he typically does. Unfortunately, Mark did not have his identification when arriving at the airport as he typically keeps it with his every-day wheelchair. Mark missed his scheduled flight and took a later flight, causing him to miss his poster presentation. Mark was able to briefly visit with the program co-director and other students in the cohort before leaving for the airport to return home. He did not attend any research presentations, career-development seminars, or social events otherwise associated with conference participation.

e) Morgan: Morgan has chronic joint pain and fatigue that makes it difficult to walk and stand for extended periods of time. Morgan uses a forearm walker as a mobility aide. Before arriving for the summer Morgan worked with the Office of Disability Services and Morgan’s research advisor to obtain accommodations to participate in the program. These included an accessible dorm room with doors that can open with a push button (installed for a student in the previous cohort), a meal plan including delivery of meals on days when Morgan was unable to walk to the dining facility, and a flexible work schedule that allowed for working in the dorm on days when Morgan experienced increased pain and fatigue. Morgan arrived by plane and was transported from the airport to the dorm by the co-director where Morgan was able to move into the room without any difficulties.

Morgan's lab group included one other student in the cohort and frequent contact with their faculty mentor who was the program co-director and a physical therapist with decades of experience working with physically-disabled persons. Another physical therapy faculty member and two other students in the cohort also worked frequently in the same laboratory space as Morgan, as well as multiple physical therapy and occupational therapy students and additional undergraduates. None of these other students had physical disabilities.

Morgan worked on integrating motion sensor hardware and software into an already existing harness system that allows people with balance deficits to participate in gardening. This included both work in an indoor laboratory and regular visits to an outdoor community garden during the summer months. Morgan worked on this project in tandem with another student in the cohort. Morgan could access both the indoor and outdoor spaces using a forearm walker and typically took breaks to sit down during the work day.

Morgan attended all weekly seminars and four of ten optional activities. Morgan travelled to the BMES Annual Conference including flying from home to Philadelphia and staying independently in a hotel room. Morgan participated fully in the conference, presenting a poster and attending technical and career development seminars.

C. Data gathering

Phone interviews of students were the primary means of understanding the challenges, facilitators, and benefits of participating in an REU program. The study also considered students' post-program focus group and annual post-program follow-up interviews. To develop interview questions the authors identified six categories of benefits of participating in undergraduate research. The first five categories were previously proposed in [17] and nicely summarize benefits of undergraduate research that have been enumerated most notably by David Lopatto [16].

1) **Thinking and working like a scientist/engineer:** Students develop critical thinking skills that can be applied in novel contexts and a greater understanding of the scientific or engineering process.
2) **Becoming a professional:** Students begin to develop a professional identity and learn the traits, attitudes, and habits of mind that are important to that profession.
3) **Personal and professional gains:** Students increase confidence in their ability to do scientific and engineering work and interact with mentors and peers.
4) **Career clarification:** Students gain experience that helps them decide between career paths.
5) **Skills:** Students learn skills, i.e. writing/speaking, programming, lab techniques, and using various software.

The authors identified a distinct sixth category.

6) **Personal growth related to living with a disability:** Students improve in self advocacy and learn about their capabilities and limits in a real-world setting.

The authors identified six themes in the literature and from experience related to the challenges physically-disabled students face in STEM majors and six parallel facilitators to students' participation. These themes are largely inspired by a recent review article on PDS in laboratories [8].

1) **Challenge: PDS are excluded from more active learning environments** or relegated to less active or observer roles [8]. Take for example a team of students working to assemble a circuit and measuring voltages across different parts of the circuit. The team might ask a student with limited dexterity to record the voltage rather than assemble the circuit or measure the voltage.
Facilitator: A project is managed in a way to allow the physically-disabled student to be an active learner. For example, the student with limited dexterity might design the circuit and direct another student to place elements of the circuit into a breadboard.
2) **Challenge: Negative attitudes of instructors and peers [4].** For example, an instructor might see a physically-disabled student as lazy or trying to game the system when asking for an accommodation.
Facilitator: Positive attitudes of instructors and peers. Instead an instructor might actively design a learning environment accessible to all students.
3) **Challenge: Physical spaces, including access to technology, limit participation [21].** In a laboratory environment high benches are not accessible to most wheelchair users. Physical or temporal spaces outside the laboratory include the dorm, the city, an outside research site such as a hospital, or a time schedule that might limit participation. The variable nature of active learning environments like field work, internships, and coops and the demands of team settings make planning for accommodations difficult [7].
Facilitator: Physical spaces, including access to technology, are designed for all or adapted for use by PDS. For example, workspaces can have adjustable table heights to accommodate wheelchair users.
4) **Challenge: Inadequate high school preparation [22].** PDS are less-likely to take and be successful in STEM courses in high school [23], [24]. For example, poor high school support services might prevent PDS from taking calculus or physics, putting them behind their peers in college engineering courses.
Facilitator: High school preparation supports participation in STEM majors.
5) **Challenge: Instructors/mentors/peers are generally unprepared to support students due to lack of knowledge [10].** For example, a well-meaning mentor might not have knowledge of various means of support (e.g. counseling services) the institution offers and hence cannot offer or refer the student to appropriate support.
Facilitator: Instructors/mentors/peers well-prepared to support students. Community building between PDS and across a diverse group of students is one way to facilitate [22]. For example, a PDS's roommate might better understand that student's capabilities and needs

and be able to offer support when most appropriate.

6) **Challenge: Financial logistics.** For the authors' experience, government benefits may be affected by students crossing state lines and how much income they receive. **Facilitator:** A program's awareness of this issue and ability to be flexible with logistics.

The program evaluator conducted semi-structured phone interviews with each student. The interviews began with ice-breaker questions allowing students to tell what they had done since the program ended. To give structure to the interview, the interviewer explicitly asked these four questions and followed-up on student responses with further probing questions.

1) Describe how well you were able to participate in the program, including living in the dorm cohort, weekly seminars, daily lab work, outside activities, and presenting to high school students and at a conference.
2) What facilitated your participation and/or success in the program both as a student in general and as a student with a disability?
3) What benefits came from your participation in the program?
4) What challenges did you face in the program both as a student in general and as a student with a disability?

For each of these questions the interviewer allowed the student to answer freely noting if the student had touched on any of the six benefits themes and seven challenge/facilitator themes described above. If the student's response did not discuss any of these themes, the interviewer asked follow-up questions to illuminate these areas. An example follow-up was "Were you able to participate in the physical spaces in the city of Cleveland, CSU campus, dormitory, and at outside activities?"

D. Analysis

The interview data were analyzed in two cycles of coding. The first cycle used a provisional coding system [25] where researchers coded excepts into the categories of benefits, challenges, and facilitators previously identified in the literature (Section II-C) or into "other benefits", "other challenges", or "other facilitators" when excepts did not match the pre-defined categories. In this first cycle each of two researchers coded half of the interviews and then all three researchers met to discuss the codes and come to a consensus on codes that differed between researchers. In the second cycle all three researchers met together and used pattern coding [25] to identity emergent themes in the existing categories. The main focus in the second cycle was to identify patterns in the "other benefits", "other challenges", or "other facilitators" categories. A secondary focus was to identify patterns in themes that were most often discussed in the provisional categories based on the literature. The number of excepts and the number of students providing excerpts in each category is reported to provide a measure of which categories were most prevalent. Themes that emerged from the second coding cycle are reported along with excepts that illustrate these themes.

The authors are confident that data saturation has been reached in this study given the sharp focus on identifying benefits, challenges, and facilitators of physically-disabled students participation in summer undergraduate research. The entire population of physically-disabled students in the program were interviewed with four of five participants interviewed more than once. Three researchers coded the interviews during two cycles in which discussions continued until the researchers converged on codes for each interview excerpt. Discussions among researchers in the second cycle continued until no new themes emerged from the data.

III. Findings

Frequencies of comments in each benefit and challenge/facilitator theme are shown in Tables II and III. Below are summaries of the comments with representative student comments for themes unique to physically-disabled students.

A. Benefits

a) Personal growth related to living with a physical: disability This category was unique to PDS relative to benefits of undergraduate research previously cited in the literature. Four of five students described this benefit.

Students improved their ability to self-advocate as PDS. This stemmed in part from making easy access to physical accommodations a focus from the start of the program:

> [The summer] experience ... helped me ... because ... I had housing that totally met my accessibility needs, and I had been in a lab environment where people weren't accommodating me because they legally had to, but because they actually wanted me to be there and valued the work that I could do. (Morgan, focused interview)

Another common theme was increased confidence in new environments gained from travelling and living away from home. Further, loved ones felt more comfortable with the students being more independent.

> The fact that I was able to do the whole summer there by myself gave us [my wife and I] both confidence ... So when I do trips for work and stuff, she's not as anxious ... She knows ... I've learned what to ask for. (Brad, focused interview)

> I had never left my home ... before on my own ... It gave me the opportunity to be my own adult ... It built up confidence that ... I could be on my own by myself or from my family. That possibility doesn't have to be some big dream, ... that it could actually happen someday. (Erica, focused interview)

Students mentioned the experience helping them to explore their own abilities and better understand their limitations:

> I learned that I'm probably not capable of working 40 hours a week, which is something that I was ... expecting to a certain extent. I knew ... that it's hard to take care of both my health and my grades. ... (Morgan, exit interview)

TABLE II
SUMMARY OF COMMENTS ON BENEFITS

Category	Total Comments	Students Commenting
Thinking and working like a scientist/engineer	6	Brad, Erica, Mark
Becoming a professional	1	Erica
Personal and professional gains	14	Brad, Erica, Morgan
Career clarification	19	Brad, Erica, Mark, Chris, Morgan
Skills	12	Brad, Erica, Chris, Morgan
Personal growth related to living with a disability	17	Brad, Erica, Mark, Morgan

b) Other benefits common to undergraduate research: All five students commented on career clarification with themes including motivation to continue in a major, exposure to different areas of rehabilitation engineering, and the choice of industry vs. graduate school. Multiple students mentioned personal and professional gains including increased confidence and ownership in independent work, a willingness to ask questions, expanding a professional network, and the chance to apply coursework to real-world problems. Students also reported improved communication skills, computer programming and specialized lab equipment. Mark mentioned the positive experience of struggling through a problem as part of the engineering process and the importance of a mentor in the lab who understood the processes. Erica described learning about the research thought process. These comments showed that PDS enjoyed benefits in much the same way as the general population of undergraduate researchers.

B. Challenges and Facilitators

a) Negative/positive attitudes of mentors and peers: Multiple students said that mentors being relaxed, supportive, and present made them approachable.

> [My mentor] didn't want everybody calling him Doctor . . . because we weren't his students, we were working alongside him . . . that was just a little more welcoming and inviting environment. (Brad, programmatic follow-up)

One student saw approachability as making seeking accommodations easier:

> . . . I definitely felt a lot more comfortable asking for things than I have in other environments, including [my home university]. (Morgan, exit interview)

Being able to connect with mentors helped Morgan see himself in the profession:

> . . . being able to . . . talk casually with [the program directors] and know that they were informed about these issues and cared was something that really shaped my sense that I do belong in academia and my willingness to advocate for my ability to be involved. (Morgan, focused interview)

TABLE III
SUMMARY OF COMMENTS ON FACILITATORS AND CHALLENGES

Category	Total Facilitator/ Challenge Comments	Students Commenting
Inclusion in active learning environments	4/1	Erica, Morgan
Attitudes of mentors and peers	18/5	Brad, Erica, Morgan
Physical spaces	15/12	Brad, Erica, Mark, Morgan
High school preparation	1/0	Erica
Mentors' and peers' preparation to support	8/26	Erica, Morgan
Financial logistics	1/2	Erica

Living and eating together fostered peer support and understanding

> . . . sometimes the other students who are in my lab would get my meal . . . and take it to me so I didn't have to walk all the way to the cafeteria and back if I was having a bad day. . . . that was really awesome. (Morgan, focused interview)

> . . . [my roommates] were very willing to give me my own space and let me do what I could. And they weren't shy about asking questions, which I see as a good thing . . . overall I would say that, in general everyone was pretty supportive and pretty good at understanding . . . (Erica, focused interview)

Morgan described the experience of other students working to fix a power wheelchair that Morgan would take home:

> . . . it was really powerful and they were excited to see how it worked and . . . [it] was really cool for them to be interested in and . . . because there's this very . . . negative stereotype about using a wheelchair. Whereas for people who use them, it's a really positive thing. (Morgan, exit interview)

Two students commented on negative attitudes of instructors and peers. These included peers assuming disability was the reason Erica was accepted to the program:

> . . . some people were even saying at my school that I got the internship . . . because [I am] in a wheelchair . . . that was kind of frustrating and hard to deal with and people aren't always supportive . . . (Erica, focused interview)

b) Physical spaces: Students commented on how working with disability services to address accessibility before the program began, accessibility of public transportation, and flexible working arrangements facilitated their full participation.

> . . . the program provided [my aide] a place to stay too. And that really helped out and allowed me to be able to participate in the whole program. . . . [They] made sure that the shower was set up the correct way . . . and the bedroom and cooking. . . . I lived right across the street from the building I had to work in,

> so that wasn't too big of a deal. But whenever we were on trips for the extra activities it was nice to know that I either had my modified van available . . . or I could also get on the city transportation . . . (Erica, focused interview)

Despite the program's best efforts, physical spaces were a challenge at times. This in turn lead to a feeling of social isolation in Morgan's case:

> . . . it was difficult, especially some days more than others to get down to the places where you could eat food. I also didn't have lunch with other people as often, and so that . . . contributed to feeling a little isolated . . . (Morgan, exit interview)

> I was a little bit concerned going into [an off-campus volunteer activity] because am I going to be able to volunteer [or] am I just gonna be sitting here? . . . but they found something that I could do . . . The only issue with that was that where they had the seating for people who were volunteering was upstairs and there wasn't an elevator. So I was sitting by myself in the accessible section for that performance, which was kind of isolating. (Morgan, exit interview)

c) Mentors and peers unprepared/prepared to support: Mentors' knowledge of accommodations makes it much easier for students to obtain them:

> . . . [my mentor] was very validating of my experiences and my physical pain and the accommodations I was requesting and suggested things that I would never have been willing to ask for. (Morgan, exit interview)

Despite this positive experience, the largest number of negative comments were related to mentors and peers being unprepared to support students due to lack of knowledge. One student needed assistance with many of her activities of daily living, so she had her aide living in the dorm with her; this required some accommodation by all involved:

> . . . since my aide lived with me, some of my peers that also lived with me, weren't always used to that . . . I'm pretty much used to that kind of situation. But, it definitely was a topic that we had talked about and addressed.. . . (Erica, focused interview)

Another student who was less visibly disabled discussed how peers did not understand his disability, especially related to fatigue and pain, and that this became socially isolating:

> . . . a lot of my friends at [my home university] are physically-disabled on some level so it was kind of difficult to be in an environment where no one knew my needs . . . it was hard to repeatedly explain that, "it's not that I don't want to spend time with you, it's that I cannot walk to eat dinner or something because then I can't get out of bed". And that's also just a very vulnerable thing to be open with, especially with your peers who are already kind of weird about being someone with a mobility impairment to begin with . . . The other challenge was definitely socially because there was not anyone else in the program with those kinds of restraints. . . . I didn't go do things with the rest of the group . . . I was like, "I really just need to be in bed right now" . . . But people didn't really understand that. And sometimes they were like, "Oh, do you just not like us?" . . . So that was kind of difficult and frustrating. (Morgan, exit interview)

Finally, Morgan also discussed supporting the identity of physically-disabled persons.

> . . . in biomedical and rehabilitation engineering, there are a lot of negative attitudes about disability . . . from my perspective, disability is not a bad thing. And that's not something that I want someone to change about me. It can be a really weird and isolating dynamic when other people tend to think of me as something to be fixed, when we're supposed to be peers or a mentor relationship . . . " (Morgan, exit interview)

d) Inclusion in active learning environments: Erica, who has limited strength and dexterity, hoped for a more hands on experience. The program directors assigned her to a lab focused on creating computer simulations because they anticipated that she would be unable to complete more physical activities such as working with hardware.

> . . . I would have liked to do something more than coding. . . . it was still a good experience. But yes, I was always looking for more of a hands on kind of thing. (Erica, focused interview)

The barrier for her may be that the program underestimated both her ability and the program's ability to facilitate her participation in more active activities:

> . . . and I think that was countered by all of the physical stuff that I got to do with the extra activities, like the lab tours and the GoBabyGo program [which required manually rewiring electronics]. (Erica, focused interview)

Morgan, who has chronic joint pain and fatigue, was able to actively participate in an outdoor garden setting with uneven terrain in the summer heat. This was facilitated by having a place to sit down and by Morgan's self confidence.

> . . . other people were physically collecting samples. And then someone would bring a chair to the location and I would sit and record measurements. I definitely felt more included at CSU or felt more like I was doing kind of an equitable portion of work. I think that a lot of that also had to do with being less personally insecure about it than I was my freshman year. (Morgan, focused interview)

e) Other challenges and facilitators: Erica required an aide for self-care activities. Her preference was to use her regular aide who worked with her before and during college. This presented a financial and logistical challenge that the program facilitated by paying for housing for the aide in Erica's dormitory suite. This was made possible with an ample program budget for such contingencies and by the dormitory typically has summer vacancies.

> The biggest thing for me was to be able to have my personal aid . . . I think that was one of the biggest things that made this opportunity possible because of insurance. It makes it quite difficult to cross state lines and I've had to go through that going to a college in Indiana and it's not easy. I was just lucky enough to be from Ohio and have the internship in Ohio. It made it possible, not easy but possible to get an aid. And then the resources provided by the program that allowed me to have my aid there with me in the dorm. (Erica, exit interview).

Students in the program have already proven to be successful in college, so high school preparation was not mentioned in the interviews except for Erica briefly discussing the individual education plan process in high school. Brad's and Chris's disabilities began after high school school.

IV. Discussion

Our goal is to create accessible summer research experiences for undergraduates with physical disabilities. Towards this goal this paper explores the benefits, challenges, and facilitators PDS experienced in participating in a residential REU program and can serve as a guide for similar programs.

Our summer program attempted to flip the script on how PDS are supported. In a typical university setting, PDS approach a central disability services office to ask for accommodations. The central office notifies faculty who may or may not be supportive and have knowledge and skills to support students. The central office then asks the faculty member to negotiate accommodations with the student that fit in with the class. This is essentially a student-led process that can result in an adversarial student-faculty relationship. In contrast, with student consent after being offered a position, the program leadership teamed with the student and the disability services office proactively before their arrival and throughout the summer to ensure an environment for success.

The REU program, with one-on-one interaction with knowledgeable faculty, a flexible schedule, and multiple locations and settings for student activities, offered an ideal "laboratory" for discovering fundamental challenges to participation of PDS and creative ways to facilitate participation. These discoveries are discussed in light of the current literature.

A. Benefits

physically-disabled students enjoyed the benefits of undergraduate research that their peers without disabilities experience [17] but with additional personal growth related to living with a disability. The program offered some students a first experience of living outside a familiar and protective setting and all the joys and challenges of that new experience. There were two ways in which the program was a great venue for developing self-reliance skills critical to the success of PDS [26]. First, students commented on family members' concerns that exemplify overprotection that can limit the potential of DS [27]. Brad and Erica saw the program as a way to prove to themselves and to their families that they can indeed succeed on their own. Second, rather than leaving students on their own to develop self-reliance, self-reliance can be catalyzed by placing part of the onus for breaking down barriers on the program. Morgan's comments about his increased self reliance returning to school highlight this. Developing self reliance is not limited to the self.

A previous report on participation of students with Attention Deficit Hyperactivity Disorder in a summer research program [28] showed that students became more interested in engineering research, increased interest in graduate school, and developed a greater sense of belonging in the engineering profession. The study did not however explore benefits specific to those students' disabilities or challenges or facilitators those students faced.

B. Facilitators

The primary facilitators of participation were positive attitudes of instructors and peers and accessibility of physical spaces. An REU is an ideal atmosphere for providing a supportive environment. Faculty choose to participate and are likely to be supportive. In a rehabilitation engineering program the vast majority of student participants had a disability, had a loved one with a disability, worked previously with disabled persons, or are at least interested in working with disabled persons. Faculty members included two physical therapists and others with previous experience working with physically-disabled persons. This was not a typical undergraduate class and instructor using a laboratory space. This kind of support lent well to flexible schedules and adapting research assignments and physical spaces to fit the student.

The interconnectedness of positive attitudes and physical accessibility facilitates participation. For instance, accessible physical spaces allowed students to eat and live together, fostering the rich discussions of disability that Erica mentioned. The approachability of mentors, mentioned by multiple students, made asking for accommodations easier.

C. Challenges

The overwhelming majority of comments on challenges concerned mentors' and especially peers' lack of knowledge on how to support PDS. Even an environment where mentors and participants best intentions are to support PDS, openly talking about disability is still a taboo. McCall et al. [29] discusses elements of engineering culture including desires to work hard and play hard as impediments to people speaking openly about disability. Morgan's experience in skipping social events in order to rest and then not feeling comfortable explaining to her peers why is a good example. In addition, McCall et al. discuss engineering's perspective that disability is another problem to be fixed; Morgan felt that this is a natural impediment to feeling comfortable in the profession.

Overcoming the taboo of discussing disability would also go a long way to both changing attitudes of instructors and peers and their lack of knowledge on how to support students – barriers to inclusion that remain even in a program designed to overcome those barriers. Too often PDS arrive in an engineering classroom with no venue to talk about disability. They may choose different strategies such as challenging expectations of engineering culture, attempt to hide their disability, or attempt to fit in with the surrounding culture [29]. These discussions can be facilitated by having students working together in labs or classes also live together, which was important in Erica's experience. Another way to facilitate open discussion is to have more than one physically-disabled student in any given group. Morgan mentioned the advantage of having people in her home environment who understand the experience of disability.

D. Study Limitations

The study was limited to five students in this program and only focused on how they experienced the program. Although the authors are confident in data saturation given the limited focus of this study, the authors are unsure of how well the results generalize to domains outside the scope of this study. These domains include groups of students with a broader set of disabilities including non-physical disabilities, other research environments, or non-research environments. This study did not examine how other facets of the students' lives affected their experience; each student was unique: one student was transgender, one suffered from PTSD, each had gender, race and socio-economic status. Research on intersectionality suggests that these characteristics impact one another, but the focus of this research was on physical disability.

This study does not discuss the perspectives of physically-disabled students' mentors or of peers without disabilities. Although educator perspectives are critical to identifying benefits, challenges, and facilitators, these perspectives tend to dominate the literature on DS as summarized in [7]. Therefore, this study is answering the call to document the often missing voices of PDS made in [8]. Anecdotally, the authors observed that peers without disabilities gained significant insight and understanding into the lives of PDS, but this finding is not based on systematic evidence. The topic of peers has received increased attention at the K-12 levels [30], but has not been widely studied on the college level, and hence is a rich area of future study.

E. Recommendations

With these limitations in mind, what follows are some best practices to guide organizers of similar programs for summer research, internships, or even for onboarding at new jobs.

- Make physical spaces accessible prior to the start date. Although this is obvious and has been discussed many times before ([7]), this effort sends the message that everyone is welcome and can be successful.
- Build program agility. Make it clear that changing schedules or physical spaces is normal. Program faculty and staff should know about students' needs; don't reserve this role to the disability services office. Communicate and make space and schedule changes on the fly.
- Create a supportive community for PDS. Shared living and eating spaces proved effective in the program. Having more than one PDS may change the social dynamic of a program for the better. Creating venues for open discussion about disability or any other differences can lead to better understanding between student participants and faculty. The program can provide faculty or peer mentors from outside the program.
- The makeup of program staff is essential. Having a rehab professional as co-director helped foresee problems and keep the system agile. Each co-director and staff member was committed to making the program successful, had the expertise to carry it out, and was accessible to students. The university willingly offered support through the Office of Disability Services.

This paper begins to meet the significant need for continued research on supporting disabled students in research environments [31]. Environments allowing students to explore original questions are quickly becoming the norm in STEM learning at the university level. However, the bulk of research has focused on one-off examples of adaptive technologies or accommodations that may be effective for specific structured laboratory or classroom spaces. With the direct comments from participants, this study answers the call to begin to understand the varied experiences of PDS in research spaces made in the most comprehensive surveys on this subject to date [8]. This initial study can begin to inform best practices that build agile learning environments to support the success of PDS in STEM education and careers.

References

[1] N. C. for Education Statistics, "National Postsecondary Student Aid Study (NPSAS: 16)," U.S. Department of Education, 2016.

[2] N. C. for Science and E. Statistics, "National Survey of College Graduates," National Science Foundation, 2017.

[3] N. C. for Education Statistics, "2012/17 Beginning Postsecondary Students Logitudinal Study (BPS: 12/17)," U.S. Department of Education, 2019.

[4] F. K. Stage and N. V. Milne, "Invisible scholars: Students with learning disabilities," *The Journal of Higher Education*, vol. 67, no. 4, pp. 426–445, 1996.

[5] M. A. Gottfried, R. Bozick, E. Rose, and R. Moore, "Does career and technical education strengthen the stem pipeline? comparing students with and without disabilities," *Journal of Disability Policy Studies*, vol. 26, no. 4, pp. 232–244, 2016.

[6] N. J. Stumbo, P. Lindahl-Lewis, and A. R. Blegen, "Two mentorship case studies of high school and university students with disabilities: Milestones and lessons," *Journal of Rehabilitation*, vol. 74, no. 3, p. 45, 2008.

[7] N. W. Moon, R. L. Todd, D. L. Morton, and E. Ivey, "Accommodating students with disabilities in science, technology, engineering, and mathematics (stem)," *Atlanta, GA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology*, 2012.

[8] H. Jeannis, J. Joseph, M. Goldberg, K. Seelman, M. Schmeler, and R. A. Cooper, "Full-participation of students with physical disabilities in science and engineering laboratories," *Disability and Rehabilitation: Assistive Technology*, vol. 13, no. 2, pp. 186–193, 2018.

[9] N. Boyer Commission on Educating Undergraduates in the Research University, Stoney Brook, *Reinventing undergraduate education: A blueprint for America's research universities*. Boyer Commission on Educating Undergraduates in the Research University, 1998.

[10] G. P. Stefanich, *Inclusive Science Strategies*. Dubuque, IA: Kendall-Hunt Publishing Company, 2007.

[11] B. S. Duerstock, L. Hillard, D. McDonagh *et al.*, "Technologies to facilitate the active participation and independence of persons with disabilities in stem from college to careers," *From college to careers: fostering inclusion of persons with disabilities in STEM*, pp. 5–30, 2014.

[12] J. D. Basham and M. T. Marino, "Understanding stem education and supporting students through universal design for learning," *Teaching exceptional children*, vol. 45, no. 4, pp. 8–15, 2013.

[13] J. Schreffler, E. Vasquez III, J. Chini, and W. James, "Universal design for learning in postsecondary stem education for students with disabilities: A systematic literature review," *International Journal of STEM Education*, vol. 6, no. 1, pp. 1–10, 2019.

[14] L. M. Meeks, N. R. Jain *et al.*, *The guide to assisting students with disabilities: equal access in health science and professional education*. Springer Publishing Company, 2015.

[15] L. M. Meeks, K. Herzer, and N. R. Jain, "Removing barriers and facilitating access: increasing the number of physicians with disabilities," *Academic Medicine*, vol. 93, no. 4, pp. 540–543, 2018.

[16] D. Lopatto, "Exploring the benefits of undergraduate research experiences: The sure survey." 2008.

[17] H. Thiry, S. L. Laursen, and A.-B. Hunter, "What experiences help students become scientists? a comparative study of research and other sources of personal and professional gains for stem undergraduates," *The Journal of Higher Education*, vol. 82, no. 4, pp. 357–388, 2011.

[18] S. R. Gregerman, J. S. Lerner, W. Von Hippel, J. Jonides, and B. A. Nagda, "Undergraduate student-faculty research partnerships affect student retention," *The Review of Higher Education*, vol. 22, no. 1, pp. 55–72, 1998.

[19] R. S. Hathaway, B. A. Nagda, and S. R. Gregerman, "The relationship of undergraduate research participation to graduate and professional education pursuit: An empirical study," *Journal of College Student Development*, vol. 43, no. 5, pp. 614–631, 2002.

[20] E. M. Schearer, M. A. Reinthal, and D. K. Jackson, "Supporting students with mobility and dexterity disabilities in a research experiences for undergraduates summer program," in *2019 American Society for Engineering Education Annual Conference*. ASEE, 2019.

[21] L. Hilliard, P. Dunston, J. McGlothlin, and B. S. Duerstock, "Designing beyond the ADA-creating an accessible research laboratory for students and scientists with physical disabilities," in *RESNA Conference*, 2013.

[22] Y. P. Weatherton, R. Mayes, and C. Villanueva-Perez, "Barriers to persistence for engineering students with disabilities," in *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, 2017.

[23] C. E. Hawley, E. Cardoso, and B. T. McMahon, "Adolescence to adulthood in stem education and career development: The experience of students at the intersection of underrepresented minority status and disability," *Journal of Vocational Rehabilitation*, vol. 39, no. 3, pp. 193–204, 2013.

[24] J. K. Martin, N. J. Stumbo, L. G. Martin, K. D. Collins, B. N. Hedrick, D. Nordstrom, and M. Peterson, "Recruitment of students with disabilities: Exploration of science, technology, engineering, and mathematics." *Journal of Postsecondary Education and Disability*, vol. 24, no. 4, pp. 285–299, 2011.

[25] J. Saldaña, *The coding manual for qualitative researchers*. Sage, 2021.

[26] C. Dunn, K. S. Rabren, S. L. Taylor, and C. K. Dotson, "Assisting students with high-incidence disabilities to pursue careers in science, technology, engineering, and mathematics," *Intervention in School and Clinic*, vol. 48, no. 1, pp. 47–54, 2012.

[27] K. Y. Sanders, "Overprotection and lowered expectations of persons with disabilities: The unforeseen consequences," *Work*, vol. 27, no. 2, pp. 181–188, 2006.

[28] A. Hain, A. E. Zaghi, and C. L. Taylor, "Board 164: Promoting neurodiversity in engineering through undergraduate research opportunities for students with adhd," in *2018 ASEE Annual Conference & Exposition*, 2018.

[29] C. McCall, A. Shew, D. R. Simmons, M. C. Paretti, and L. D. McNair, "Exploring student disability and professional identity: navigating sociocultural expectations in us undergraduate civil engineering programs," *Australasian Journal of Engineering Education*, pp. 1–11, 2020.

[30] H. E. Travers and E. W. Carter, "A systematic review of how peer-mediated interventions impact students without disabilities," *Remedial and Special Education*, p. 0741932521989414, 2021.

[31] A. Lillywhite and G. Wolbring, "Undergraduate disabled students as knowledge producers including researchers: A missed topic in academic literature," *Education Sciences*, vol. 9, no. 4, p. 259, 2019.