
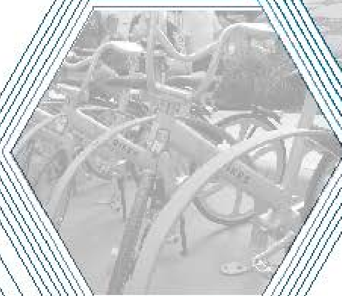

Campus as a living lab: Discovering the comfort of wheelchair users in the pedestrian network by experiential learning with high school students

June Young Park
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FINAL REPORT

Center for Transportation Equity, Decisions & Dollars

CAMPUS AS A LIVING LAB: DISCOVERING THE COMFORT OF WHEELCHAIR USERS IN THE PEDESTRIAN NETWORK BY EXPERIENTIAL LEARNING WITH HIGH SCHOOL STUDENTS

FINAL PROJECT REPORT

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Sponsorship:
CTEDD

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16. Abstract
Although the adoption of the Americans with Disabilities Act (ADA) shifted our paradigm for accessibility, the built environment is still not friendly for wheelchair users. The main challenge is that enforcement of ADA guidelines primarily focuses on the design requirements, while actual usability is less emphasized in current practice and evaluation is limited largely to walk-through investigations. In this project, we used on Disability Studies and data-driven approach to develop and implement an experiential learning-based curriculum to teach students about disability-related transportation inequities. The curriculum aims to introduce the mobility barriers encountered by wheelchair users—one of the largest minority user groups of transportation infrastructure. The curriculum also covers the educational contents of open source-based data acquisitions (e.g., Arduino, sensors) as well as data analytics (e.g., descriptive statistics, data visualizations) with multiple hands-on examples. After completing each module, the research team used the University of Texas at Arlington campus as a living lab for high school students via which they demonstrated their data acquisition tools and present the results. This series of educational activities provided experiential learning opportunities for upper-level high school students interested in careers in engineering and introduce them to basic concepts in Disability Studies and disability-led design. With the successful completion of the proposed project, the curriculum motivated high school students to develop citizen science-based solutions and to be aware of disability-related barriers when they encounter other transportation inequities in the future.

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Citizen Science, Disability-led Design, Experiential Learning, Mobility, Open-Source, Wheelchair Users

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Abstract

Although the adoption of the Americans with Disabilities Act (ADA) shifted our paradigm for accessibility, the built environment is still not friendly for wheelchair users. The main challenge is that enforcement of ADA guidelines primarily focuses on the design requirements, while actual usability is less emphasized in current practice and evaluation is limited largely to walk-through investigations. In this project, we used on Disability Studies and data-driven approach to develop and implement an experiential learning-based curriculum to teach students about disability-related transportation inequities. The curriculum aims to introduce the mobility barriers encountered by wheelchair users—one of the largest minority user groups of transportation infrastructure. The curriculum also covers the educational contents of open source-based data acquisitions (e.g., Arduino, sensors) as well as data analytics (e.g., descriptive statistics, data visualizations) with multiple hands-on examples. After completing each module, the research team used the University of Texas at Arlington campus as a living lab for high school students via which they demonstrated their data acquisition tools and present the results. This series of educational activities provided experiential learning opportunities for upper-level high school students interested in careers in engineering and introduce them to basic concepts in Disability Studies and disability-led design. With the successful completion of the proposed project, the curriculum motivated high school students to develop citizen science-based solutions and to be aware of disability-related barriers when they encounter other transportation inequities in the future.

Chapter I: Introduction

Frist, we explain the mobility barriers encountered by wheelchair users and the importance of educating high school students on data acquisition and analytics. Then, we describe the unique history of UTA's longstanding commitment to serving students with disabilities, i.e., a history that makes UTA a uniquely effective living lab. Lastly, we introduce the campus as a living approach to adopt our educational contents to train students as future citizen scientists.

Approximately 2.7 million people in the U.S. use wheelchairs, making them one of the largest minority groups in transportation. In addition, people with disabilities are the largest minority group in the U.S. and the world. The population of Americans who use wheelchairs is constantly renewing (WHO, 2020). This means everyone in the U.S. has a high chance to join this minority group. If they live long enough. Although the adoption of the American with Disabilities Act (ADA) in 1990 shifted our paradigm of accessibility, the built environment is still not friendly for wheelchair users (Titchkosky, 2011). The main challenge is that enforcement of ADA guidelines mainly focuses on design requirements, while usability is less emphasized in current practice and evaluation is limited largely to walk-through investigations (Welage & Liu, 2011). To mitigate these limitations, researchers have used crowdsourcing data to develop knowledge of wheelchair accessibility in urban environments (Mobasheri et al., 2017). However, the efficacy of crowdsourcing is often limited by high-level components (e.g., a focus checking the numbers of ADA parking lots) rather than recording the actual perceptions of wheelchair users. In fact, wheelchair users often experience seat discomfort from the poor road conditions, which consequently impacts the personal environmental conditions (e.g., thermal comfort, air quality) of wheelchair users (Meyers et al., 2002) and which can also cause chronic pain and pressure sores. Therefore, we need to shift our paradigm again to measure the comfort of wheelchair users by data acquisition and then use analytics to assess the accessibility of our urban environment.

Since the late 1960s, the University of Texas at Arlington (UTA) has led the nation in helping students with disabilities gain access to educational opportunities. In 1968, UTA undergraduate students established the Handicapped Students Association (HSA), one of the first organizations of disabled students in the U.S. and soon convinced University administrators to make the campus accessible well ahead of federal mandates. In 1974, the HSA, administrators, and the Texas Rehabilitation Commission partnered to work towards a "barrier-free model campus" and established the office for students with disabilities, and an adapted sports program in 1976. Reflecting UTA's long history of serving students with disabilities, UTA hosts the first degree-granting Disability Studies program in the South. Treating disability as a crucial element of human diversity and human experience, the Disability Studies Minor approaches disability as a social, political, and cultural construct rather than just a medical condition. Today, the UTA Movin' Mavs and Lady Movin' Mavs wheelchair basketball teams (established 1976 and 2013) are nationally renowned, and 30 alumni and current students have competed in the Paralympics. UTA libraries also hosts one of the only disability history archives in the country, the Texas Disability History Collection, which preserves and makes available the history of how UTA students and administrators turned the campus into one of the most physically and attitudinally accessible in the country.

To implement the educational modules that we develop, we adopt UTA campus as a living lab, capitalizing on a campus that was, in effect, designed since the late 1960s in part for wheelchair users and which hosts many faculty, students, and staff who use wheelchairs. A living lab is an open real-life environment where actual users of the place can co-create and innovate new services, products, and societal infrastructures (Bergvall-Kareborn & Stahlbrost, 2009). Several academic campuses have actively used their campus environments as living labs. Most previous living lab studies focused on sustainability objectives and have shown that campus community members can achieve sustainability goals through their own actions. In sum, living labs can play a significant role in addressing community members' challenges in campus environments and envisioning the most effective solutions to those challenges. Such an approach also fits with the tenets of Disability Studies and disability-led design, which center disabled people's experiential knowledge and vie disability not as something to "fix" or "eradicate" but as a generative, creative force in design (Fried et al., 2005).

Chapter II: Education Objective

We develop and implement an experiential learning-based curriculum to teach the challenges of transportation inequity and relevant skills. Figure 1 summarizes the three main education objectives in this project. The first objective is to introduce the mobility barriers encountered by wheelchair users, who are considered one of the largest minority user groups of transportation infrastructure. It is more effective to learn via hands-on experience, therefore, the second objective is to provide experiential learning opportunities to collect and analyze the data related to wheelchair users. We develop lecture modules for data acquisition using open source-based hardware (e.g., Arduino, sensors, circuits) as well as basic data analytical techniques (e.g., descriptive statistics, data visualization, critical thinking). Students visited UTA campus to demonstrate their data acquisition tools with actual wheelchair users and present their findings. Lastly, the third objective is to motivate high school students to develop citizen science-based solutions and incorporate awareness of disability-related barriers and the importance of disability-led design when they encounter other transportation inequities in the future.

Our project aligns well with the CTEDD's educational objectives. Our new curriculum advanced current STEM education program in high schools by training future citizen scientists to understand the challenges of transportation inequities and help them to develop relevant skills (i.e., data acquisition, data analytics). Our approach was directly applied into an engineering class from Garland ISD (Texas). Our educational activities directly provide mentorship for upper-level students interested in careers in a STEM field by teaching data acquisition and data analytics skills.

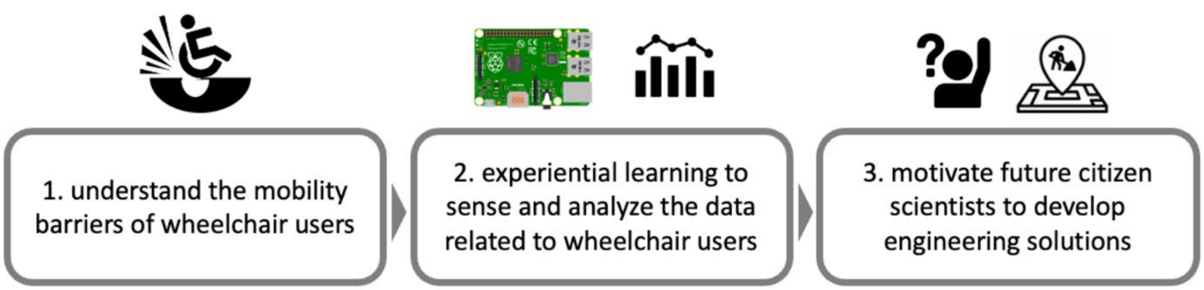

Figure 1. Project overview

Chapter III: Educational Contents Development

This chapter explains how we prepared our educational contents and the main idea of each lecture module.

Preparation Meetings

As the initial activity, we met with all stakeholders including other UTA community members. The main objective is to understand the various mobility barriers encountered by wheelchair users (a diverse group who may use manual, power-assisted, or power chairs or scooters) of UTA and key factors in their comfort. The other stakeholder group is high school teachers to gather their feedback for our educational plan. We use Microsoft Teams, which offers broad disability accessibility.

Table 1. Contents development meeting minutes

Date	Participants	Main agenda
8/31/2021	Park, Eisma, Salazar	• Covid restriction on student teaching • Stakeholder meeting • TA recruitment • Curriculum brainstorming
9/14/2021	Park, Eisma, Salazar	• IRB application for wheelchair user involvement • TA recruitment job notice (Engineering)
9/28/2021	Park, Eisma, Salazar	• IRB application for wheelchair user involvement • TA applicants interview and discussion (Engineering) • Finalize the contents of the curriculum
2/1/2022	Park, Eisma, Rose, Salazar	• The course contents update and discussion • Implementation plan with GRCTC and CityLab
2/11/2022	Park, Eisma, Rose, Salazar	• Finalize the lecture contents • TA recruitment (Disability Studies) • Scheduling and modes for lecture delivery
2/14/2022	Park, Eisma, Rose, Salazar	• The data acquisition part (hardware) is demonstrated • Course material discussion (Disability Studies)
2/18/2022	Park, Diaz	• Course contents check with Carmen (a high school teacher) • Schedule and logistic to visit GRCTC
3/1/2022	Park, Eisma, Rose, Salazar	• Fix the detail teaching schedule • Discuss the activity with wheelchair users
3/4/2022	Park, Diaz, Oswaldo	• Finalize the teaching schedule with GRCTC • Decision to drop CityLab
3/22/2022	Park, Eisma, Rose, Salazar	• Rehearse the course contents • Discuss post-lecture activities

Table 1 summarizes our meeting agenda to discuss the curriculum development. We met 10 times before the lecture delivery in March, 2022. Not only just the project team but also high school teachers and wheelchair users were involved in our discussion to give their feedback on our lecture contents. Their involvement in our curriculum development was absolutely critical as they reframe our lecture into understandable levels from high school perspective as well as some contents were emphasized and removed based on wheelchair users' active suggestion. It is important to note that education contents of a new topic such as citizen science for wheelchair users should include actual stakeholders in order to describe the matter comprehensively. Another change from our original plan was to drop CityLab high school for our lecture plan due to the confliction of both school academic schedules. We posted our job notice with Civil Engineering department and Disability Studies distribution email. Through a competitive application and interview process for each applicant, we recruited three undergraduate teaching assistants (TA; two Engineering major students and one Disability Studies minor student) from underrepresented ethnical group.

Curriculum Development

We develop a curriculum for high school students. This curriculum consists of three main topics: 1) Disability 101, 2) Data Acquisition, and 3) Data Analytics. We led the content development based on our individual expertise. The lecture contents were developed based on the project PIs' previous educational contents (e.g., data acquisition tools to monitor environmental quality & data analytics of building energy meter data; Disability 101, History of Disability, Introduction to Disability Studies). The pedagogical approach mixes brief lectures with some discussion and many activities. Multiple hands-on examples are incorporated to allow students time to practice the contents by themselves. The final developed lecture contents (slides, Jupyter notebook, Arduino code, hardware configuration) are digitally archived and publicly available upon the request to the project PI's email.

1. Disability and built environment: The first topic introduces students to disability and basic Disability Studies concepts, ADA design guidelines and the concept of disability-led design, and the importance of human comfort in the built environment. The human-centric approach in design and construction (O'Brien et al., 2020) and disability-led design is introduced to train students as future citizen scientists and ensure that they are aware of disability barriers going forward.

In this first session, we define disability and discuss the models (i.e., medical model, social model, functional model) of disability by providing examples of accessibility. First, the medical model is a consequence of a health condition, disease, or the result of a trauma. Such type can only participate fully in society after their impairment has been cured. Then, the social model explains that a person is limited not by their disability but by the social and physical obstacles imposed onto them from their environment. The barrier is a result of a lack of social organization and prevents people with disabilities from full participation. Lastly, the functional model is caused by physical, medical, or cognitive deficits. This type limits complete functionality or the ability to perform function activities. The team deliver the knowledge of such models as well as led the discussion. The topic includes 1. How do you or your family define disability? 2. How does society define disability? After the discussion, the team introduce the concept of universal design as a mitigation solution in the built environment.

The next session, we applied our knowledge of universal design into our own campus (both high school and UTA campus). For this activity, we prepared some photos from our campuses to promote student-led discussion. The example discussion is described as follows.

Figure 2. Example photos used for student-led discussion

Figure 2 might be a problem for someone with a disability because it can cause smaller wheels of wheelchair users to get caught in the crack and potentially flip their chairs. This also indicates uneven bricks around campus which can cause wheelchair users to fall out of their chairs. This is important to fix, especially at the end of ramps, as the chance of injury increases with higher speeds when going down ramps. In the right image of Figure 2, tiny pebbles on sidewalks cause vibrations which cause discomfort for people with disabilities. In addition, uneven surfaces/change in surfaces or large gaps not only cause discomfort but can affect push if someone is not aware. To overcome, the University can ensure that cracks in concrete or flooring is filled/fixed to avoid incidents.

<u>*2. Data acquisition (WheelCom):*</u> We teach open-source hardware as the main data acquisition tool. With the increasing use of open-source hardware in education and communities (Heradio et al., 2018), our approach encourages more students to experiment with their ideas and show them how to use such experiments to answer their intellectual questions. An Arduino is used as the main controller. We specifically teach the usage of accelerometer and air quality sensors to measure the seat and environmental comfort (thermal comfort, air quality) of wheelchair users, respectively.

Various environmental conditions are taken into consideration when looking at wheelchair users discomfort. Most of the conditions focus on the users personal environment, e.g., thermal comfort, air quality, and local vibrations. The other variables looked at involve the local time and location to find probable causes of discomfort. These conditions are going to be grouped together to find correlation between either 2 sets of conditions to link them together. Patterns was also analyzed to see if similar sources of discomfort can be detected with telemetry alone as opposed to using an auditor. Data was analyzed through exploratory data analysis to find other potential sources of discomfort.

WheelCom is an environmental sensing toolkit used for understanding wheelchair users (dis)comfort (Figure 3 (top)). This tool was specifically designed for high school students to learn data acquisitions of environmental values for wheelchair users. It is based on the Arduino platform. Peripherals used are an ADXL-345' accelerometer (1), an Adafruit micro SD card reader (2), DHT-20 temperature and humidity sensor (3) and a PM25 PMS 5003 Particle Sensor (4). Locations and local time are observed with a GT-U7 GPS unit (5). These modules are connected via a central breadboard and jumper wires to a single Arduino Uno (6). All values are recorded via an SD card reader module. Power for the unit is provided through a single 9V battery. The unit takes a recording of the wheelchair user's personal conditions and location roughly every second and writes it to a csv file on the SD card. These hardware components were chosen based on being readily availability and cost effective. The conceptual design was meant to be easily construct-able to promote citizen science and DIY assistive technology (Hurst & Tobias, 2011, October), these designs were tested in a high-school curriculum with students able to assemble the hardware quickly and correctly with simple instructions within hours.

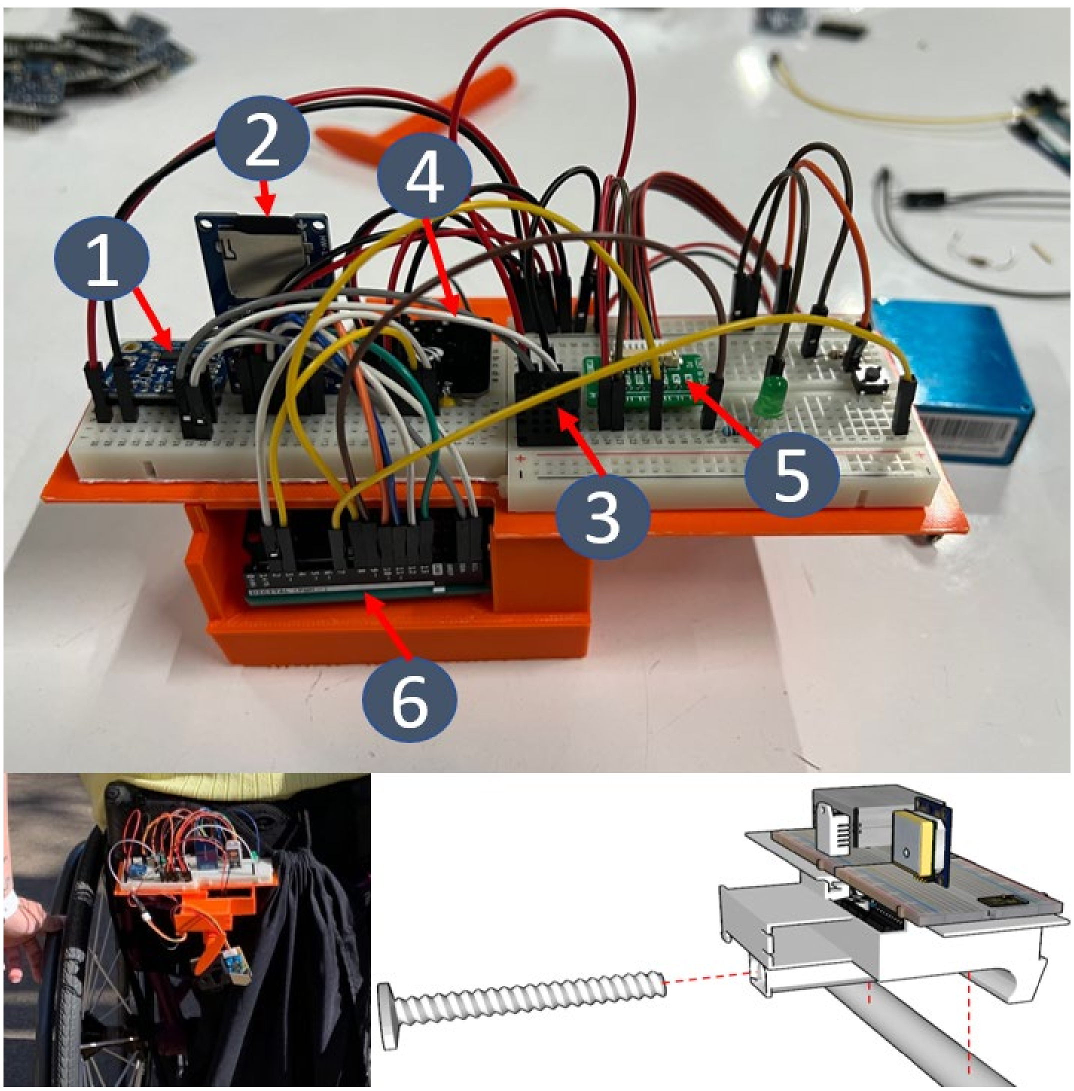

Figure 3. *WheelCom* overview (Top: circuit and sensors, bottom: installed on a wheelchair by the customized 3d printed case)

The sequence of operations for data logging follows pulling data objects, parsing info from them and storing only the needed portions of data, the rest is then discarded. This happens from sensor to sensor to maintain free memory. Some sensors like the ADXL and the DHT sensor use the I2C protocol, others used asynchronous serial communication, like the GPS transmitter and PM2.5 sensor. The data is written in small blocks to the SD card to prevent stack overflow. To be able to read from two different serial devices in operation, software serial switching was used. To keep the serial devices synchronized for logging input data, loops were used to wait until a proper data packet entered. Once all required data is collected then it is written to file in a csv format. TinyGPS++ was used to parse GPS data to minimize RAM usage. The sampling rate was limited to 1 cycle/second due to synchronizing serial sensors for input, namely the GPS sensor as it only would populate data once a second.

The entire setup is encased in a customized 3D printed case with the intention of being affixed to the rear brace bar that was found on each chair to keep placement consistent (Figure 3 (bottom)). The 3D printed case was designed in Google Sketch-up, the overall design criteria for this case was the easy assembly and interchange of components for different applications. ABS plastic was the material of choice for the case due to it's low cost. The method of affixing the case to the Wheelchairs used a clamp design so as to account for different sizes and designs of wheelchairs. Small rubber pads were used to prevent slipping and rotating of the device. The Arduino itself slips onto 4 standoffs, one with a threaded hole and the remaining 3 to have alignment pegs. The top shield of the case was designed to slip on and off easily to access the Arduino if needed, a breadboard is mounted to the top with bonding tape. The Arduino jumper connections are left exposed for easy access, if quick adjustments are needed.

3. Data Analytics using a Jupyter notebook: The last lecture topic covers data analytics. Considering the importance of data science in STEM education, we introduce the basic data analytic skills to engage more students in STEM fields. The final topic includes exploratory data analysis, descriptive statistics, data visualization, and data-driven critical thinking.

The last lecture topic covers data analytics. Considering the importance of data science in STEM education, we introduced basic data analytic skills to engage more students in STEM fields. One of our goals during this session was to provide the students with basic programming skills and tools that they could apply to other projects or in their own lives. Therefore, we used the easily accessible Jupyter Notebook and the Python programming language to facilitate the data analytics lesson. The lesson included exploratory data analysis, descriptive statistics, data visualization, and data-driven critical thinking, as described below. The data analyzed during the lesson was collected by Senior Personnel Salazar during a trip around UTA's campus and included measurements from each sensor attached to the Arduino.

The data analytics lecture was designed with the assumption that the students were programming novices. After discussing the capabilities of Jupyter Notebook and common Python libraries (e.g., NumPy, Pandas), we taught the students how to import data from a .csv file and to filter the data. To filter the data, we removed all rows that had missing data or were erroneous. Satisfied with the quality of the remaining data, we introduced basic statistics concepts like mean, median, mode, standard deviation, and quartiles. At this point, we shifted from a lecture-based lesson to a hands-on lesson. We provided the students with a handout of a fully commented and executed Python code and asked them work through it. The project team was available to answer questions on an as-needed basis and would occasionally stop the class to ask questions that gauged the students' learning and understanding of the content.

During the student-led portion of the data analytics lesson, students wrote and executed code on data visualization and descriptive statistics. The data visualization included generating not only standard plots like scatter plots and line plots but also involved statistical plots (e.g. violin plot, box-and-whisker plot) and an example from the GeoPandas library. The GeoPandas example taught students how to lay the data on top of a basemap of campus, so the data points were in the right place. This was a critical step for enabling the students to connect their data with physical features on UTA's campus and to understand anomalies in the data that may have been caused by changes in surface material, cracks, etc. Overall, the lecture went well after addressing a few minor issues that arose when the students were familiarizing themselves with Jupyter Notebook and Python. We are confident that the students enjoyed the lesson, particularly the student-led portion, and learned skills that they could translate to other areas of their lives.

Chapter IV: Education Activities

This chapter describes three educational activities to implement the developed educational contents as a curriculum of high school students.

Lectures at GRCTC

We visited Gilbreath-Reed Career and Technical Center (GRCTC) to implement the proposed curriculum for high school students. GRCTC provides opportunities for students to take advanced-level career and technical education courses in addition to taking other classes at their home campus. One of their educational topics focuses on engineering, and GRCTC offers an onsite experiential learning program. The proposed curriculum aligns well with both schools' missions, where we provided the knowledge and skills to design, build, and participate in the future development of the city to serve all citizens. Ms. Carmen Diaz (a high school teacher at GRCTC) supported actively to successfully deliver our lectures to students.

Table 2 summarizes our lecture schedule to visit GRCTC. There were two groups (A & B) under Ms. Carmen Diaz's Engineering class. Group A and B has 16 and 21 students, respectively. We visited GRCTC three times. The first two lectures (3/29/2022 & 3/31/2022) were delivered virtually by the instructors' requests whereas we conduced on-site visit for the lecture of 'data acquisition & analytics' to provide hands-on examples. Figure XYZ & XYZ shows how we delivered both lectures with GRCTC.

Table 2. Lecture plan

Date	3/29/2022	3/31/2022	4/5/2022
group A (7:15am-10:15am)	Disability 101	No lecture	Data acquisition & analytics
group B (11:40am-2:40pm)	No lecture	Disability 101	Data acquisition & analytics

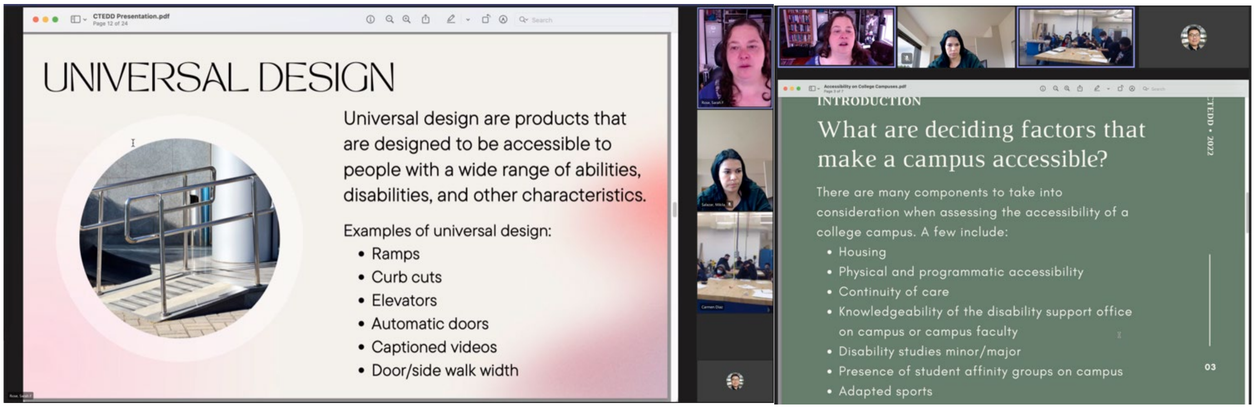

Figure 4. Virtually lecturing 'Disability 101' (on 3/29/2022 & 3/31/2022)

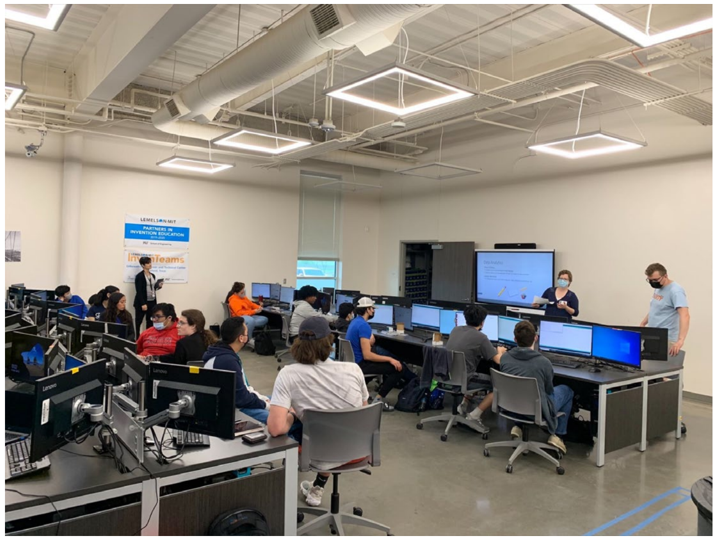

Figure 5. Lecturing 'Data Acquisition & Analytics' (on 4/5/2022)

A debrief event for high school students at UTA

After teaching the educational contents, we hosted an education debrief event for high school students. They visited the UTA campus to demonstrate their data acquisition tools and present their findings. The event was conducted on 5/19/2022 and the total duration is 3 hours (1hour: open project discussion led by the team, 2 hours: student presentations led by Ms. Carmen Diaz). For the student presentations, we provided the pre-collected data from a wheelchair user to high school students in advance so that they present their analysis during this event at UTA. Each team presentation (2-3 students for one team) was around 10 minutes and there were 13 teams in total. Based on the quality of presentation, the research team (instructors and TAs) decided the top 3 teams to award Arduino start kits as present. Finally, each team submitted their final development of *WheelCom*.

Figure 6. A debrief event for high school students at UTA

Deploying *WheelCom* with Movin' Mavs

Each submitted *WheelCom* units by high school students are then deployed by actual wheelchair users at UTA. This experiment is designed for identifying the challenges of air quality for wheelchair users by a community effort (i.e., device developed by local high school students, measurement conducted by wheelchair users). Although this activity is not part of education plan but this indeed emphasize why we educate our future generations in STEM to identify any social inequity problem in the built environment. We recruited 10 wheelchair users from the Movin' Mavs wheelchair basketball team in this experiment, one device for each chair. The experiment was held over the course of roughly 1 hour, on 6/16/2022. The experiment was held on UTA campus. Participants were asked to go in groups of either 1 or 2, and follow a single path that is typical of their daily routine. A proctor accompanied each group of students to document any discomfort the students had. When a student voiced concern about something that has either caused discomfort or can cause discomfort, it is then photographed and tagged by location. Results are then pulled from each machine and consolidated to be analyzed. The whole experiment process was approved by Institutional Review Board (IRB) office.

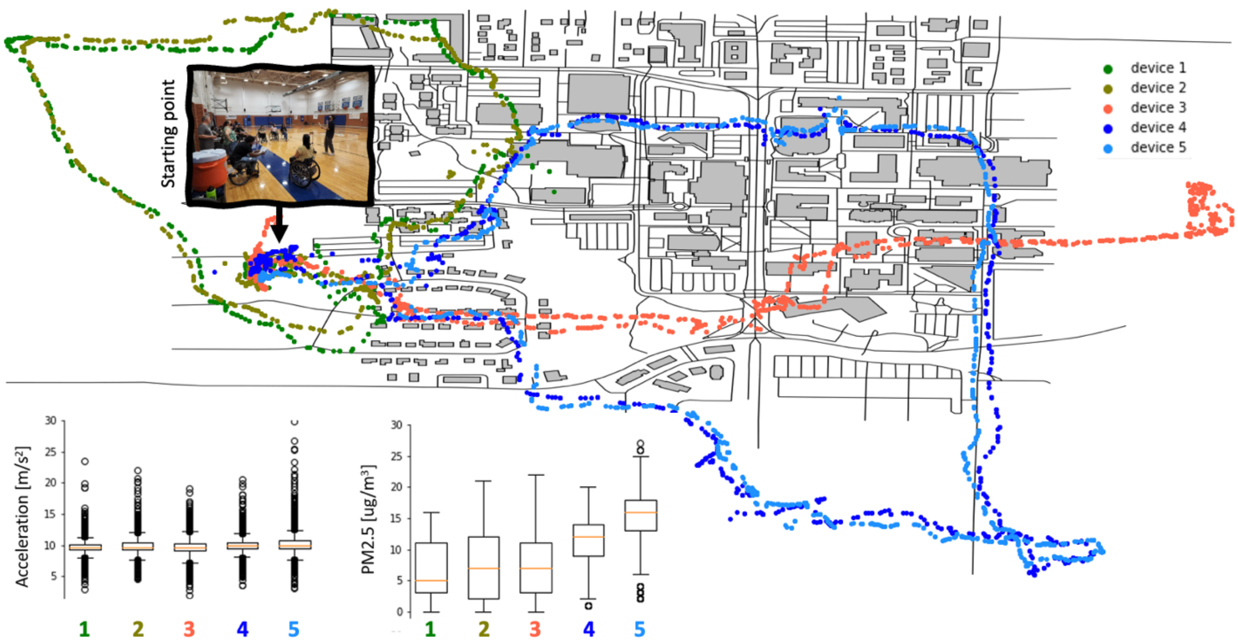

Figure 7. *WheelCom* deployment results

Figure 7 visualizes five routes from wheelchair users with *WheelCom* measurement. Starting from the basketball court of the team, device 1 & 2 went to the West side, device 4 & 5 went to the East side, and device 3 went through the center of the campus. The right bottom inset figures indicate box plots of acceleration and PM2.5 grouped by each device. Instead of strictly using Z-axis values for acceleration, the resultant vectors intensity is calculated. The assumption is that the most intense acceleration is going to be felt in the vertical axis as a bump is crossed, this is also to account for the device possibly slipping or rotating during the test, changing the axes. Figure 8 shows the imposed map image of each variable. Obviously, the acceleration values are distributed very narrowly around the Earth gravity (9.8 m/s^2). Based on previous literature (Sonenblum et al., 2012), the higher acceleration values indicate some seat discomfort for wheelchair users (e.g., pothole, crack, pavement change, leveling issues). Particle count levels are taken directly from the unit as ug/m^3. Typically, higher particle count levels are found closer to streets and busier intersections. The Environmental Protection Agency (EPA) recommends to keep PM2.5 levels to 12ug/m^3 or below to maintain respiratory health while being sure to not be exposed to sudden spikes over 35ug/m^3. While device 1, 2, & 3 showed fairly low mean values, the routes from device 4 & 5 had relatively higher PM2.5 values.

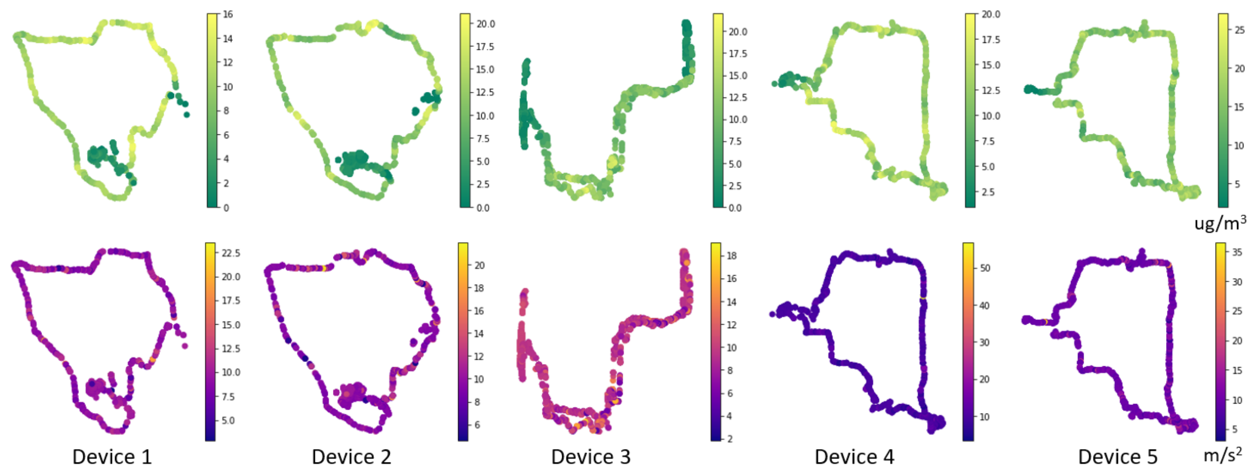

Figure 8. Five routes by PM2.5 concentration and acceleration

From the observation of both acceleration and PM2.5 data, we investigated the correlation between the two. In fact, there was no shape-wise similarity between the two time series patterns since both are noisy and contain other compound factors. Figure 9 indicates a snapshot of the data collection of device 5. It clearly shows first sharp acceleration increase before 550 second and delayed response of PM2.5 increase after 550 second. These sharp acceleration increases are not usually associated with poor design but rather infrastructure failures such as potholes, cracking sidewalks, or expansion joint separation. This physically explains that those failures of infrastructure management may generate seat discomfort (high acceleration) first and the rotation of two wheels moves dust toward wheelchair users upper level (e.g., chest, head, nose). To confirm our anecdotal evidence, we systematically evaluate the observed relationship across the five devices. Figure 10 indicates the 95% confidence interval of PM2.5 values of 30 seconds after it detects the significant acceleration increase (>15m/s^2). Although their patterns are all different, it is clear that all five devices show the increasing trends of PM2.5 values after their shape acceleration increase. They are all above 12ug/m^3, which is the guideline from EPA, and the route from device 5 was the worst experience for the wheelchair user.

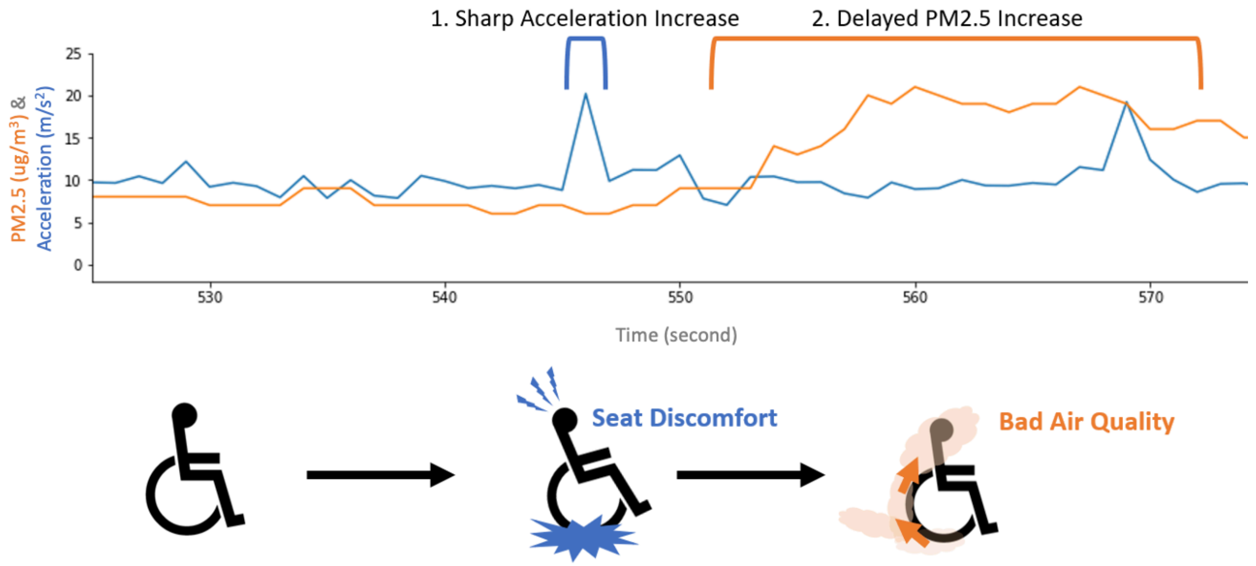

Figure 9. A snapshot of both PM2.5 and acceleration for device 5

Wheelchair users have physical obstacles; however, the results from this experiment show that potentially other factors can affect a wheelchair user. If a user has discomfort from an uncomfortable pathway that causes their chair to shake as they move, they might also have an issue with dust potentially as well as seen in our results. Our results also point to sharper impacts bringing about more intense changes in PM2.5 levels. The weather during the test was clear, with minimal cloud coverage and no fire weather warnings, PM2.5 levels were shown to be at or below 12 for that day. Car traffic was typical around busy streets, the higher PM2.5 levels shown around street intersections can be explained by car traffic disturbing dust and debris on the street as well as vehicle exhaust in proximity. The campus had minimal traffic as the test was performed during a summer semester, the wheelchair users and proctors were the only people using the pathways on campus. It is possible that with more foot traffic (e.g. during a fall semester), higher levels of PM2.5 concentrations could occur on all walkways and in turn have higher spikes around walkway failure. With a lower breathing zone it is likely that this would impact wheelchair users even more than those that are ambulatory.

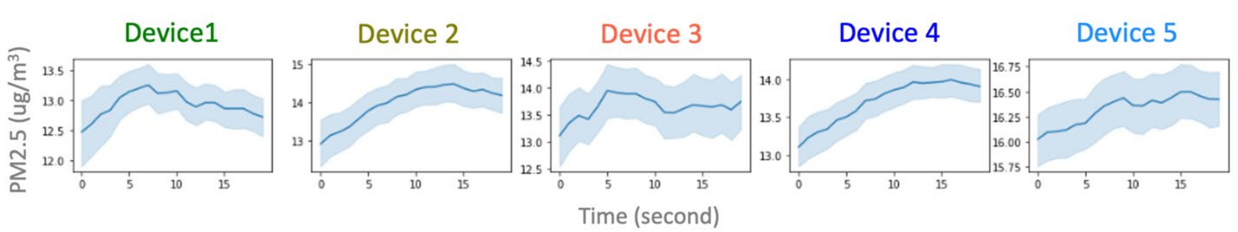

Figure 10. PM2.5 trends after detecting a significant acceleration change

Chapter V: Conclusion

In Civil Engineering, minor design changes can have major effects on the comfort of wheelchair users around urban infrastructure. For instance, in the results discomfort was had by all users around campus: 1) rode over pebble paths, 2) the brick trim used to separate spaces on pathways, 3) separation of the expansion joint in concrete walkways cause wheels to become stuck or potentially cause users to fall, 4) the holes left where walkway bollards mount cause severe issues with wheelchair users, note that these holes do not have plugs and are full of debris and dust. However, there is little that they can do to avoid these paths and such paths generates not only their seat discomfort but also potential air quality issues.

The hardware part of our education program, *WheelCom*'s application in this study was focused on wheelchair users, however the methods and tools used here can be used in a variety of applications e.g. monitoring conditions for children in schools. In addition to this, the primary focus of the units used here were to monitor air quality and the kinematics of the wheelchairs themselves and seeing how they affect users. Another form of discomfort that can be monitored by these devices could be thermal comfort and more of the biological aspects of the users, like monitoring metabolic levels and surrounding humidity and temperature. *WheelCom* was successful in it's primary task, more research must be done to see what is possible to link other education goals.

We clearly showed that the community efforts (i.e., high school student-led development and wheelchair user measurement) were successfully conducted to identify wheelchair users' discomfort by the proposed education program. Although we conducted our experiment with only 5 devices, the proposed education program will be easily implemented in any high school classroom. This will ultimately cover more areas for wheelchair users. To discover any potential inequity challenge of wheelchair users, it is necessary to first collect more data from our own community, and this paper started its small educational contribution toward the environmental equity for wheelchair users.

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Appendix A: Lecture contents

All lecture contents will be publicly available upon the request to the project PI's email.

Appendix B: Technology Transfer

An Appendix should be included in this final report to document the Technology Transfer activities conducted during the project term, accomplishments towards T2 adoption and implementation by relevant stakeholders, as well as any relevant post-project T2 plans.

The main technology transfer was conducted from our lecture contents to actual teaching at GRCTC (a high school in Garland ISD). For the successful technology transfer, we communicated well with Ms. Carmen Diaz who teaches engineering at GRCTC. Ms. Diaz directly assisted the project team with curriculum development. The classes taught by Ms. Diaz was the primary targets for the educational content, with content delivery occurring during the Spring 2022 semester. The educational content includes hands-on and active learning to address this issue; the exposure to Disability Studies and disability-led design also introduced students to concepts rarely taught in high schools but which are relevant to the everyday experiences of many. As Ms. Diaz implement the module in their classrooms over the years, it may evolve to focus on sensing and analyzing other questions about the urban environment.

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