Developing an affordable air purifier to enhance air quality across New Delhi, India.

By Anish Garg

- **CREST Award Level:** Gold
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- **Date: 2nd April 2025**

Abstract

The project is aimed at developing a cost-efficient air purifier to address the dual challenges of affordability and effectiveness in combating air pollution. This was particularly motivated by the dire air quality in places like Delhi, where pollution levels during certain months significantly impact health, especially for underserved communities such as gig workers and building guards who lack access to adequate solutions. The study compared the performance of two commonly used filters—HEPA and activated charcoal—using an Optical Dust Sensor and Arduino Nano in a controlled AQI environment. Results indicated that the HEPA filter was significantly more effective in reducing PM2.5 concentrations, while activated charcoal showed limited usability. Based on these findings, a personalized air purifier prototype was designed with HEPA filters, featuring a nozzle for targeted air delivery and a fan to enhance purification rates. The prototype was optimized for affordability through 3D printing and designed with low-cost manufacturing and maintenance in mind. Testing revealed that the purifier effectively reduced particulate matter in the immediate vicinity, offering a practical solution for improving air quality and mitigating health risks, especially respiratory conditions.

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Introduction

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In India, opulent families can afford air purifiers capable of reducing harmful particulates like PM2.5 and PM10 by 99.5%.

However, the vast majority of Indians, including groups like building guards, gig workers, and low-income households, lack access to these devices due to limited disposable incomes and high costs. These underserved populations often live in close proximity to pollution sources such as factories and manufacturing hubs, exacerbating their exposure to harmful air quality. Addressing air pollution is a global priority, essential to achieving the UN Sustainable Development Goal 3, which emphasizes good health and well-being by 2030. Affordable and accessible air purification solutions are critical to mitigating the adverse health impacts of pollution, particularly for those most vulnerable. By developing cost-effective air purifiers tailored to the needs of such groups, we can bridge the gap in equitable access to clean air and create healthier living environments.

Project Objective

To evaluate various filters to determine the one with the highest filtration efficiency and design a 3D personalised air purifier model that incorporates the optimal filter to ensure cleaner air for the user.

- Test and analyze the HEPA and activated charcoal filter under controlled conditions.
- Develop basic C++ programming skills to program and calculate a running average for the AQI
- Design and prototype a cost-effective, portable 3D model incorporating the optimal filter.
- Expand my knowledge of advanced air filtration principles and 3D modeling techniques
- Used as an education tool to raise awareness and protective measures as well.

The personalised air purifier is conceptualized to ensure users from lower economic strata and gig-economy workers can access clean air, reducing the long term impacts of continued exposure to poor air quality. The product should be distributed to the masses such as security guards or delivery drivers who spend excessive time outside.

Literature Review

Air pollution, as defined by the World Health Organization (WHO), involves the contamination of indoor or outdoor environments by chemical, physical, or biological agents that alter the natural characteristics of the atmosphere. Common pollutants include particulate matter (PM2.5 and

PM10), carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. Globally, air pollution was responsible for 8.1 million deaths in 2021, making it the second leading risk factor for mortality, with 99% of the global population residing in areas with unhealthy air quality. In India, particularly in Delhi, hazardous air pollution reduces life expectancy by an average of ten years, with major contributors being construction and dust (45%), waste burning (17%), transport (14%), diesel generators (9%), domestic sources (7%), and industrial processes (8%). The wider purpose for the project is to address the severe health and environmental impacts of air pollution by identifying and implementing sustainable solutions. Given that 99% of the global population breathes unhealthy air and pollution significantly reduces life expectancy, especially in Delhi, this project aims to raise awareness and develop a innovative strategy to mitigate pollution sources.

Comparison with other literature:

Research Paper	**Summary of Findings**	**Challenges**
Environmental Research Letters	The researchers modeled scenarios where 50% of existing open urban greenspaces were transformed into forests and found that this large-scale conversion would result in only about a 1% reduction in urban PM2.5 concentrations.	Minimal Reduction in PM 2.5
U.S. Environmental Protection Agency's research with regard to ion generators	Ion generators work by charging airborne particles, causing them to settle on surfaces or be collected within the device. While they may remove some small particles, they do not effectively remove gases or odors and are relatively ineffective against larger particles like pollen and house dust allergens	Cause various health issues, including being a lung irritant
EffectiV HVAC UV Light	UV light filters typically consist of a UV lamp housed within a protective chamber. It is exposed to the UV light, which disrupts the DNA of microorganisms, rendering them inactive or unable to reproduce.	High cost and severe maintenance requirements

Resource and Training

I entered this project with a basic foundation in CAD designing due to my experience in the F1 in Schools competition but needed to develop advanced modeling skills, including creating complex surfaces (for the holes in the personalized model), and parametric designs. I learnt this through YouTube tutorials. I enhanced my understanding of 3D printing, learning to prepare models using slicing software, adjust printer settings for different materials, and troubleshoot common printing issues. I started with fundamental C++ knowledge but expanded into microcontroller applications using the Arduino Nano. By referring to official documentation, tutorials and taking help of my CS teacher at school, I learned to interface sensors and control outputs.

I approached this project under the guidance of a mentor, whose instructions provided direction and clarity throughout the development process. While I was responsible for executing the work, my mentor's input ensured I stayed on track and approached challenges with effective solutions.

Timeline

Phase	Tasks	Duration
Ideation	Identified the issue of rising air pollution in Gurgaon and its health impacts. - Brainstormed solutions focusing on a large-scale air purification system installed within the HVAC system as part of a social work initiative. - Researched existing air purification technologies to find gaps and opportunities for improvement. Went under multiple observanships with car and bike mechanics to discuss improvements in filtration systems of engine. Talked to multiple guards and delivery drivers about the most common issues they faced. Decided to build a cost effective air purifier.	2

Filter research	Conducted in-depth research on various filter types (HEPA, activated carbon, electrostatic, etc.) to determine the most efficient one for Gurgaon's pollution levels. Designed and assembled the electronic circuit controlling the dust sensor. Programmed the system using the Arduino Uno for automation and data collection Created an initial 3D model of the filter housing	3
Testing	Carried out multiple tests to evaluate the efficiency of different filters under various environmental conditions. Monitored air quality parameters (PM2.5, PM10, AQI) before and after filtration to measure effectiveness.	1.5
Development of the 3D model	Worked on developing a personalised air purifier using the filter Gave the first filtration system to my society guard and asked him to keep a track of how he felt for 15 days Meanwhile, incorporated design features based on the feedback he gave Continued working on this iterative process three to four times	3
Consumer Feedback	Conducted surveys and interviews with potential users to understand practical needs and preferences. Collected feedback regarding size, noise, maintenance, and effectiveness. Redesigned the nozzle to optimize air intake and distribution while minimizing	.5

	power consumption. Made the filtration exchange system more robust .	
Writing and Documenting CREST report	Working on the documentation of the CREST report Continually incorporating mentor feedback	1.5

Methodology

Concise Methodology:

Step 1: Testing the HEPA and activated charcoal filter on their effectiveness in filtering particulate matter.
Step 1(i): Integrating the Optical Dust Sensor, with an Arduino Nano, to measure and compare the efficiency of each filter and their combinations in improving air quality.
Step 1(ii): Developing a laser cut model of acrylic sheets to test the efficiency of different filters
Step 2: Developing a personalized air purifier incorporating features such as nozzle for targeted clean air distribution and a fan to enhance the airflow and purification rate.

Step 1(i) Coding the Dust Sensor:

The first step was to program the dust sensor to calculate the Air Quality Index (AQI). This was done using the Arduino IDE with C++. The dust sensor measures the concentration of particulate matter (PM). To convert the sensor's raw data into AQI values, I used predefined breakpoints that represent thresholds for PM2.5 concentrations and their corresponding AQI levels.

```
const float PM25_BREAKPOINTS[] = { 0.0, 12.1, 35.5, 55.5, 150.5, 250.5 };
const int AQI_VALUES[] = { 0, 51, 101, 151, 201, 301 };
```

The sensor readings were processed into a running average to ensure consistent, reliable results, which were then displayed to the user.

```
dustDensity = dustSensor.getDustDensity();
runningAvg = dustSensor.getRunningAverage();
```

When the measured PM2.5 value falls within a specific range, the program calculates the AQI using interpolation between the corresponding breakpoints. This ensures accurate AQI values even for measurements that do not exactly match the predefined thresholds.

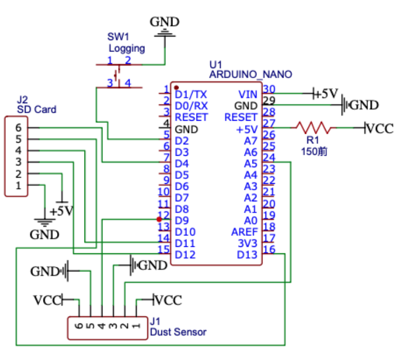
```
float pm25Low = PM25_BREAKPOINTS[i - 1];
float pm25High = PM25_BREAKPOINTS[i];
int aqiLow = AQI_VALUES[i - 1];
int aqiHigh = AQI_VALUES[i];

aqiValue = aqiLow + (aqiHigh - aqiLow) / (pm25High - pm25Low) * (pm25 - pm25Low);
```

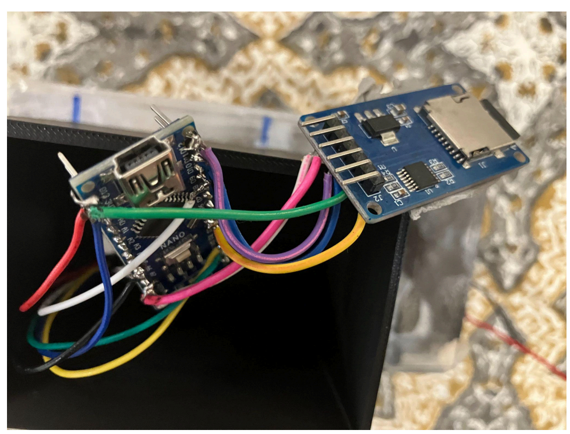
The final AQI is presented to the user in real-time, providing an intuitive understanding of air quality conditions.

```
Serial.print("PM 2.5: ");
Serial.print(dustDensity);
Serial.print(" ug/m3; Running average: ");
Serial.print(runningAvg);
Serial.print(" ug/m3");
Serial.print(" AQI: ");
Serial.print(AQI);
Serial.print(" Logging: ");
```

Creating the circuit diagram:

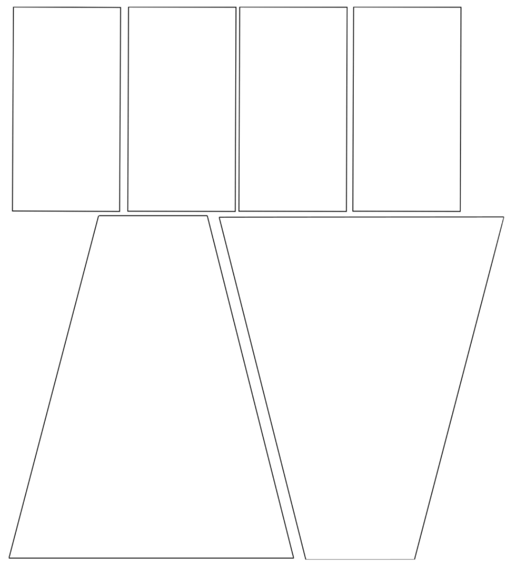
This circuit features an Arduino Nano connected to a dust sensor and an SD card module. The Arduino collects air quality data from the dust sensor and saves it to the SD card. The circuit is powered by a 5V supply. This circuit is connected to an SD card to store the data.



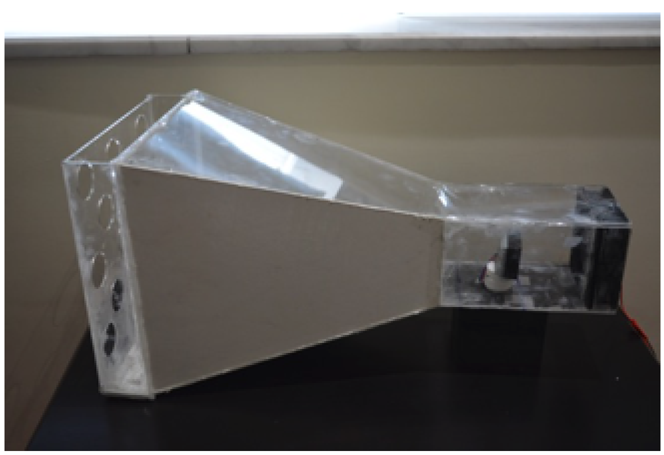


Developing a CAD model for the wind tunnel to test the filters:

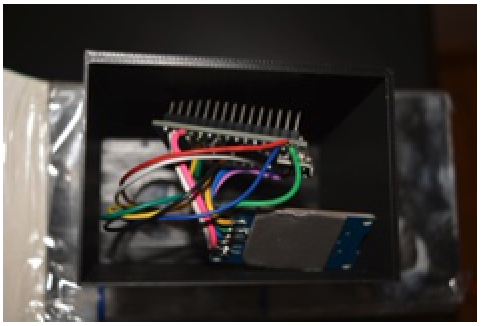
I developed a CAD model of a wind tunnel specifically designed to optimize air quality measurements using a dust sensor.



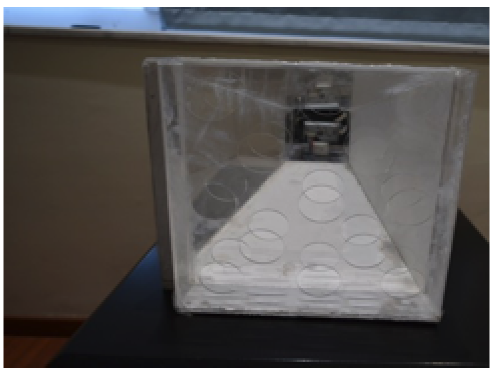
These are the 3D drawings which were then laser cut on acrylic sheets. The wind tunnel was constructed from the laser-cut acrylic sheets, which were then assembled using hot glue and tape to ensure a sturdy and airtight structure.



The dust sensor was placed at the end of the box, while a fan was added to the other end to increase the airflow rate through the tunnel. To house the dust sensor circuitry, I designed and 3D-printed a black enclosure. This box not only protected the circuitry but also served as a leveling base for the testing tunnel.



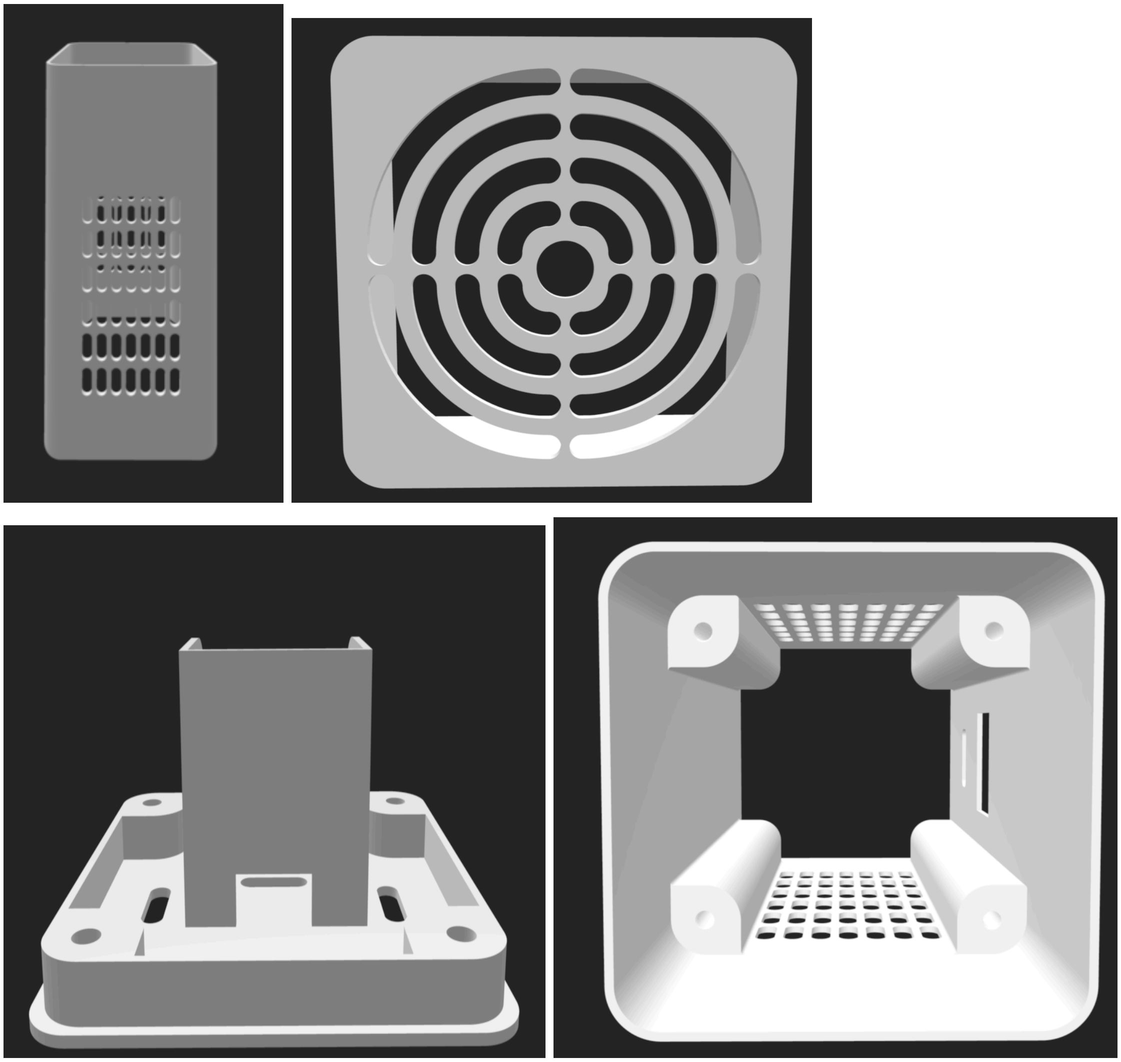
However, a design flaw emerged during the assembly phase. The measurements of the acrylic box, specifically the section intended to hold the air filter, were slightly inaccurate. This resulted in a small opening in the structure. To address this issue, I improvised by covering the gap with a cardboard sheet.



While this fix resolved the immediate problem, it may have introduced minor deviations in the AQI measurements.

Cost of the Testing Model:
Acrylic Sheet + Laser Cutting: ₹600
Sensor Module: ₹1100
Fan Cost: ₹100

Step 2: Personalised Air Purifier:



CAD Design

Prototype Model

Prototype Model on a table

This is the current model using HEPA filters. The design features holes throughout the structure to enhance air purification, with securely placed filters inside the box to improve airflow. Currently, the power supply relies on an adaptor, but a rechargeable battery system will be incorporated. To further enhance performance, a nozzle will be added to ensure cleaner air in the vicinity, and a fan has already been integrated to increase the rate of air purification. The personal air purifier will be designed based on the filter efficiency results. It will take a cuboid shape, allowing air intake from all sides, while the top section ensures efficient air exit. Additionally, a nozzle and fan will be included to optimize air purification.

The cost breakdown of the model is as follows:

3D printing: ₹300
Fan: ₹100
Filters: ₹250

Material Used:

Material	Model
Dust sensor	SHARP GP2Y1010AU0F Dust Sensor (Analog Output) general purpose (0 to 1500 µg/m3

Arduino Nano	Arduino Nano
SD card module	DFRobot Fermion: MicroSD Card Module for Arduino (Breakout)
Wires	Mechatron Robotics 20cm Male to Male Breadboard Jumper Wire (Pack of 40)
Laser-cut acrylic sheets	Asmi Collections Laser Cut Clear Transparent Acrylic Sheet for DIY (4 mm, 12x12 Inch)
Hot Glue	Hot Glue Gun
Tape	Tape
Fan	12 volt High Speed DC 3" Big Size CPU Cooling Fan
3D printer	Bambu Lab X1 Carbon Combo 3D Printer
Cardboard sheet	White Cardboard sheet
Air Filter	HEPA and Activated Charcoal Filter
Power Supply	Standard 12V 2A Power Supply with 5.5mm DC Plug
Design software	Autodesk Fusion 360
Soldering iron	Soldering Iron 25w

Safety and Ethical Consideration:

Safety and Ethical Considerations	Improvements
Electrical Safety – I was going to use a 3D printer and a soldering iron, both of which can reach high temperatures and cause permanent skin damage.	To improve safety, I ensured that I was always with an adult while using these tools and operated the soldering iron strictly under supervision.
Waste Generated by Multiple Prototypes – Since the design went through multiple iterations, this led to significant material waste.	To minimize waste, I limited the number of times I printed the system and focused on incorporating feedback through digital renders before physical production.

Using strong adhesives such as a hot glue gun and sharp tools like cutters and pliers.	To prevent cuts and burns, I wore gloves while handling both tools.

Results

I tested the HEPA filter and the Carbon Filter and tested them in the same environment using the wind tunnel. They were tested on statisitcial measurers such as mean, median, and mode. The key finding was that the HEPA filter did reduce the air pollution and those results were significantly consistent. However, the average PM2.5 in both the filters was still higher than the safe threshold recommended.

<u>Activated Carbon Filter</u>

PM 2.5 Readings taken from Activated Carbon Filter (AQI)	
93	111
103	111
106	110
109	111
111	111
111	111
110	109
110	110
110	109
114	111

PM2.5	Analysis
Mean	109.2
Standard Error	0.9963089777
Median	110.5
Mode	111
Standard Deviation	4.455629201
Sample Variance	19.85263158
Kurtosis	9.52608286
Skewness	-2.848399142

The analysis of the PM2.5 levels after using an activated carbon filter for an air purifier shows that the mean concentration is 109.2 µg/m³, with a median of 110.5 and a mode of 111, indicating a consistent clustering of values around the average. The standard deviation of 4.46 reflects minimal variability. The negative skewness (-2.85) highlights occasional lower PM2.5 values, while the high kurtosis (9.53) points to a sharp peak. The small sample size of 20 limits generalizability.

HEPA Filter

PM 2.5	
97	105
96	102
93	103
95	102
96	103
96	102
96	100
96	95
97	93
99	105

PM2.5	Analysis
Mean	98.45
Standard Error	0.8318495562
Median	97
Mode	96
Standard Deviation	3.72014431
Sample Variance	13.83947368
Kurtosis	-1.334461911
Skewness	0.2455670958

The PM2.5 data after applying the filter shows a noticeable improvement in air quality. The mean concentration is 98.45 µg/m³. The median (97) and mode (96) are close to the mean, suggesting a symmetrical distribution and consistency in performance. The small sample sizes limits how we can generalize this data.

The results show that the HEPA filter is more effective in filtration. This study used a single layer of HEPA and activated charcoal filters. While HEPA filters are more expensive, both filters were selected within an affordable price range. Existing studies require advanced multi-layer filtration technologies to meet WHO standards, increasing costs. Although ionization and UV filtration are more effective, they are expensive and not easily scalable. Our achieved standard, however, significantly improves the situation.

Comparison with existing products:

Market Solution	Comparison
	This is the product I will use to compare my air purifier. While it has superior filtration efficiency and longer-lasting filters, it has critical flaws: A) It is not affordable, making it inaccessible to most consumers. B) It lacks portability, preventing gig-economy workers from using it to reduce air pollution on the go. **Cost: ₹6,500**
	This is a car air purifier. While it is affordable and meets the basic goal of reducing air pollution, it has several flaws: A) It requires a constant power supply, meaning it must stay connected to an external source. In contrast, my device runs on replaceable batteries. B) The filter maintenance cost is high. For gig-economy workers who need frequent replacements, this leads to increasing expenses. **Cost: ₹2,500**

Challenges:

Procurement of materials was challenging as I was unsure which material to use for the 3D-printed box while ensuring environmental sustainability. Time was another constraint—I am in Grade 11, pursuing the IB DP program, which comes with its own project challenges. Balancing my academics with work on this air purifier and incorporating feedback was difficult. Additionally, my mentor was not very responsive, requiring me to frequently follow up for feedback, which slowed progress. Another challenge was understanding some user feedback, leading to frustration on both sides. On the technical side, we faced difficulties with measurements in relation to the air purifier. Moreover, understanding and implementing the code was challenging, leading to numerous difficulties and errors. Lastly, finding a way to make the entire project more eco-friendly proved to be a complex task. One major challenge I overcame was optimizing the air flow efficiency. While the purification was normal, I realised that the rate was extremely slow. To fix this, I increased the number of holes that were there and added a fan which aided in both. Another issue was that the design was limited by being placed in a constant power supply through a power adaptor. To address this issue, I decided in the next iteration I will include a battery module which makes the device portable and aids with the gig economcy workers.

Summary of Finding:

The study highlights the effectiveness of an activated carbon filter in reducing PM2.5 levels, as seen in the significant improvement between the two datasets. The mean PM2.5 concentration dropped from 109.2 µg/m³ to 98.45 µg/m³, accompanied by reduced variability and more consistent performance. However, despite this improvement, the levels remain above the recommended safe threshold, indicating that while the filter is effective, it may not be sufficient as a standalone solution for achieving optimal air quality. Using a combination of HEPA and activated carbon filters could offer a more comprehensive approach by addressing both particulate matter and gaseous pollutants. However, this may not always be cost-effective due to higher initial costs, maintenance expenses, and energy consumption.

Successes of the product:

Test and analyze the HEPA and activated charcoal filter under controlled conditions.	- Successfully tested both the filters through a wind funnel arrangement. - Design flaw in measuring the wind tunnel dimensions that could have reduced the accuracy of the test
Develop basic C++ programming skills to program and calculate a running average for the AQI	- Developed Ardunio IDE coding through C++, and read research on calculating the running average for AQI - Integrated multiple programs for

	different sensors to calibrate and record information in relation to calculating the AQI
Design and prototype a cost-effective, portable 3D model incorporating the optimal filter.	- Designed a prototype model with holes and fan, using the HEPA filter to achieve cleaner air purification in the vicinity - Added a design for the nozzle to increase the equilibrium of clean air particles
Expand my knowledge of advanced air filtration principles and 3D modeling techniques	- Did learn about ionizing air purifiers, UV light air purifier, and carbon air purifiers - Didn't focus on achieving the physis behind increasing te rate of air purification
Used as an education tool to raise awareness and protective measures as well.	- Wasn't able to education any about the air purifier and the design principles behind it - Wasn't able to mass produce the air purifier

Future Work:

Future work will begin with testing the nozzle-incorporated system to evaluate its effectiveness and determine whether it provides a meaningful improvement in air purification, considering cost constraints. To facilitate large-scale testing and production, establishing a contact with manufacturing facility capable of producing over 1,000 units will be essential. This will help refine the production process, ensure quality control, and assess scalability. Additionally, a new model will be developed to integrate a more affordable air filtration system into HVAC systems. This innovation aims to enhance indoor air quality on a larger scale while maintaining cost-effectiveness and energy efficiency.

My role as both the creator and implementer of this project has been insightful. Having previously worked in a team, this experience was inspiring as I navigated the challenges of working independently and being accountable for all deadlines. Completing each milestone was a learning experience in itself. Every failure—whether difficulties in programming the dust sensor or challenges in assembly measurements—proved to be valuable and impactful. Through this project, I gained skills in implementing consumer feedback, developing effective models, and ensuring precision. I overcame challenges by maintaining an open mind and approaching each step as a new milestone in the journey. Moving forward, my key recommendation is to document all information coherently for better organization and future reference.

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I would like to extend my thanks to my mentor for guiding me throughout the entire process, providing direction, and offering support on specific technical aspects when needed.Lastly, I would like to thank my parents for funding the necessary hardware and components required for the project.

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Appendix:

Formula for AQI:

$$AQI_{value} = AQI_{low} + \left(\frac{AQI_{high} - AQI_{low}}{PM_{2.5high} - PM_{2.5low}}\right) \times (PM_{2.5} - PM_{2.5low})$$