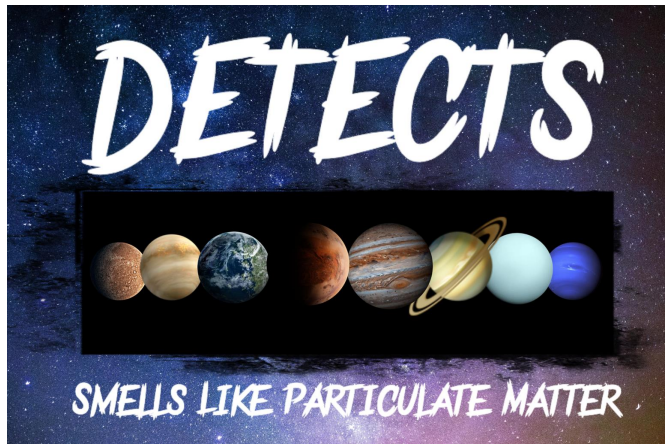
System Acceptance Review

Smells Like Particulate Matter
Palmetto Scholars Academy
Team 1

DATA EVALUATION FROM TESTING VIA AN EDUCATIONAL CHALLENGE WITH TEACHERS & STUDENTS

DETECTS



Palmetto Scholars Academy

DETECTS
SMELLS LIKE PARTICULATE MATTER

Team Lead
Michael
Blunt
11th Grade

Experiment Lead
Max
Freedman
11th Grade

Experiment Group
Benjamin
Deaton
11th Grade

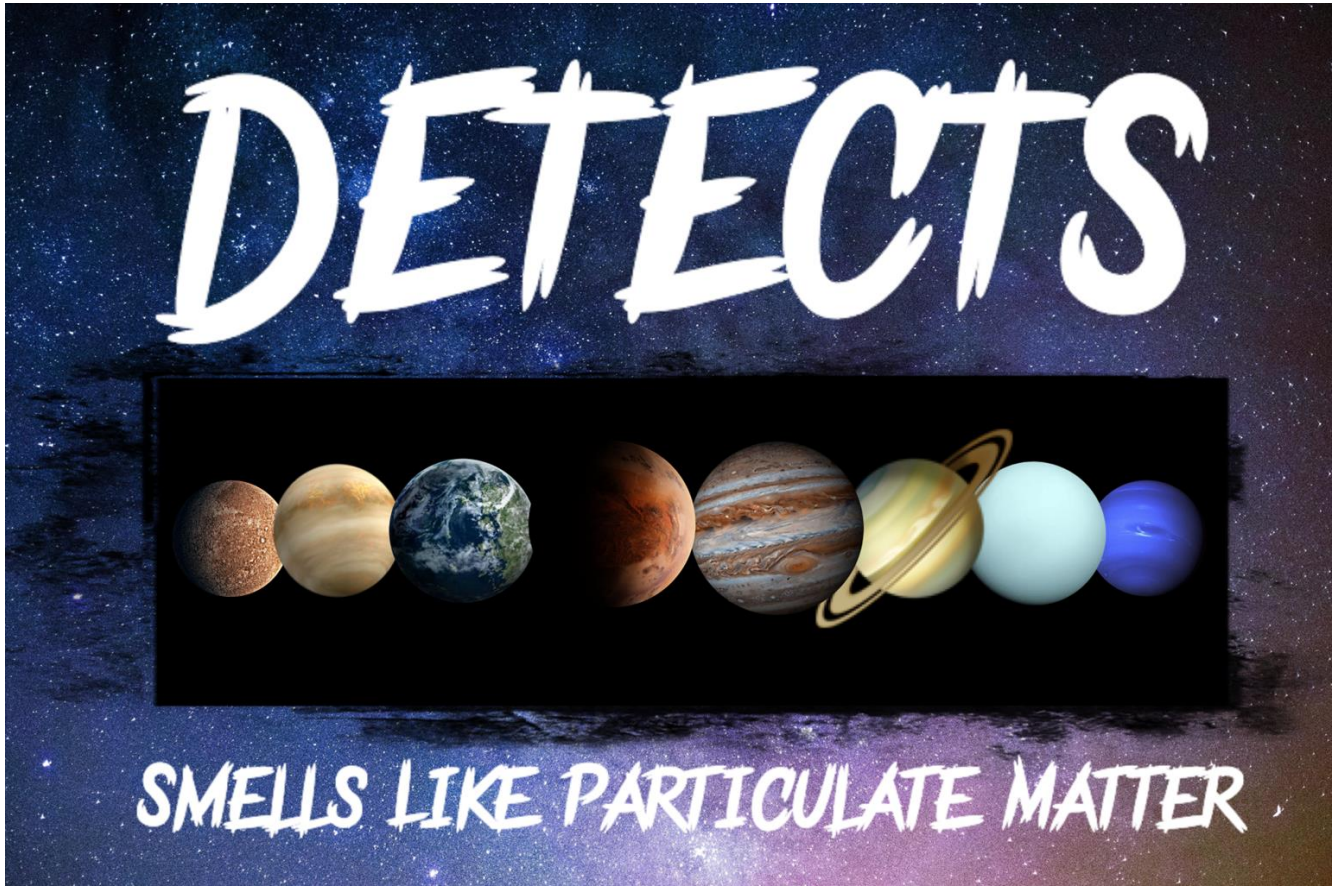
Chief Engineer
Samantha
Quartuccio
12th Grade

Test Lead
Emann
Rivero
12th Grade

Test Group/Outreach
Morgan
Peterson
11th Grade

DETECTS

Smells Like Particulate Matter



"[Our] goal is simple. It is a complete understanding of the universe, why is it as it is and why it exists at all" – Stephen Hawking

ACES RED 2B

- Studying quantum entanglement for space satellite communications.
  - Sponsored by U.S. Space and Missile Defense Command (SMDC)
- Secondarily investigating the use of low-cost commercial-off-the-shelf (COTS) hardware
  - To replace currently used expensive equipment
  - Primary objective of DETECTS

https://space.skyrocket.de/doc_lau/falcon-9.htm

Design Requirements

Mechanical/Spatial Requirements	Electrical Requirements
• Must be no larger than 65 x 56.5 x 19mm • Must be less than 19mm above the surface of the Pi when plugged in	• NO High-voltage-inducing instruments (over 28 V) • Pinout used must be the one found on the Pi • Pins 30 and 31 cannot be used
Material Requirements	**Software Requirements**
• NO Mechanisms or moving parts • NO Liquids, gases, or fluids of any kind • NO Organic material or any other exotic material • NO Vibrating/oscillating components • NO Loose/powdered material • NO Batteries or electrolytic capacitors	• Must be developed on a Raspberry Pi 3B+ • Must operate the Pi HAT and gather data from it • Data rate must NOT exceed 5 kilobytes per second • Must communicate with the AR2B flight computer via JSON formatted packets • Transfer JSON packets into a folder called /tmp/experiment/ in the Raspberry Pi's file system • Must include an identifier within the JSON packet

Experiment

Chosen Science Objective

- **Science Objective**
  - Establish an experiment that can compare the quality and quantity of data gathered by commercial-grade and professional-grade particulate matter sensors.
  - Assess particulate density, prevalence, size, and levels over time in ACES RED 2B using consumer-grade sensors.

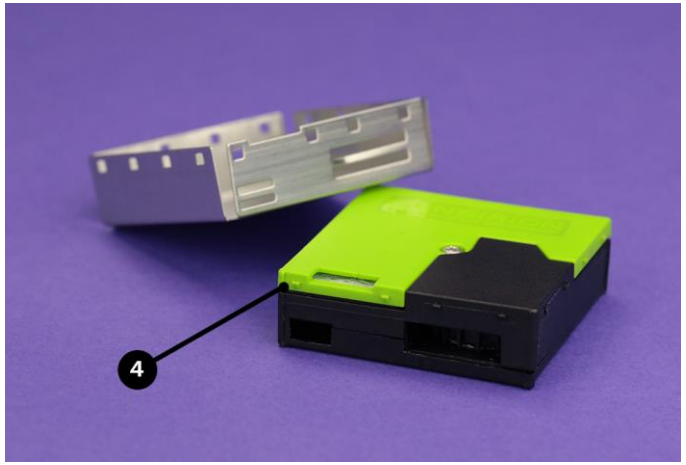
Hypothesis

- **Research Question**
  - What is the difference in both quality and quantity of measurement between consumer and professional-grade sensing technology?
- **Hypothesis**
  - Laser based consumer-grade particulate matter sensors are more accurate than existing professional-grade infrared particulate matter sensors.
- **Research**
  - ANITA, developed in the early 2000s for ISS
  - > 0.7 µm (high parts per billion) - Infrared
  - > 0.3 µm (low parts per billion) - Laser

Sensor - SPS30

The SPS30 particulate sensor is a very small and accurate consumer grade sensor.

- dimensions: 40.6mm * 40.6mm * 12.2mm
- min detectable: 0.3µm diameter
- output: digital (I^2C)
- accuracy: ±10 $\mu m/m^3$
- long-term drift: ±1.25 $(\mu m/m^3)$/year
- laser/infrared: laser

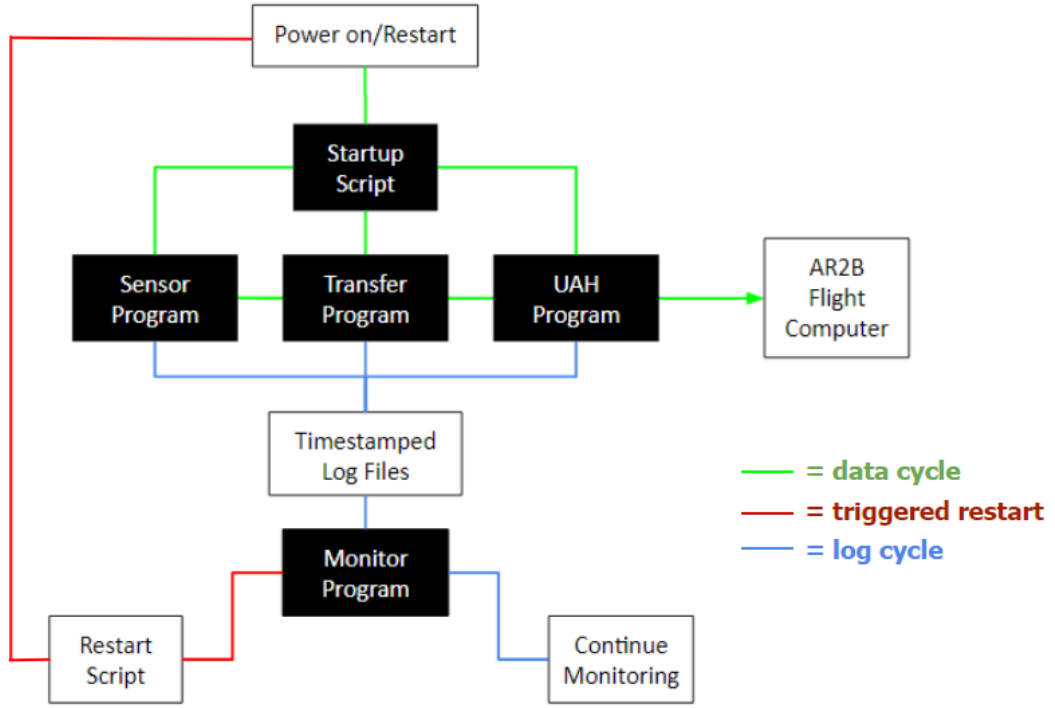


Experiment Design

Phase 1
- Powers on (crontab).
- Launches all other programs in a structured order.
- Turn on SPS30; ensure data flow.

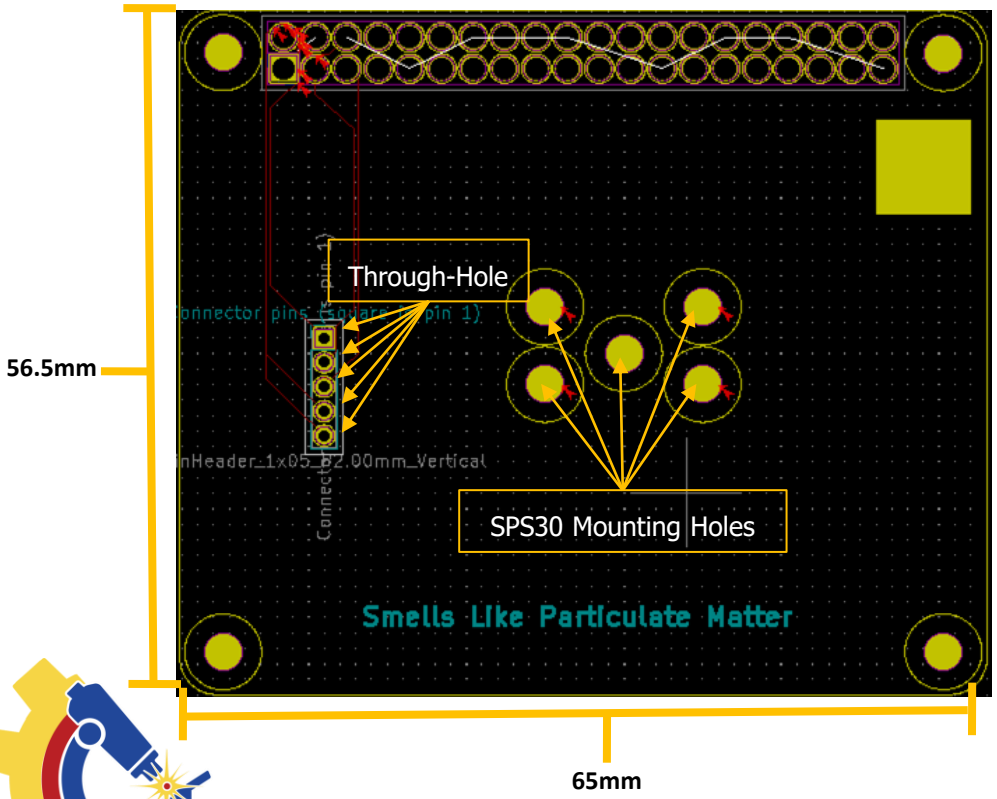
Phase 2
- Continuous operation with a 12 hour (on) 2 minute (off) cycle.
- Verifies continuous program functionality with a monitor program.
- Sends data until 14 days before AR2B end-of-life cycle.

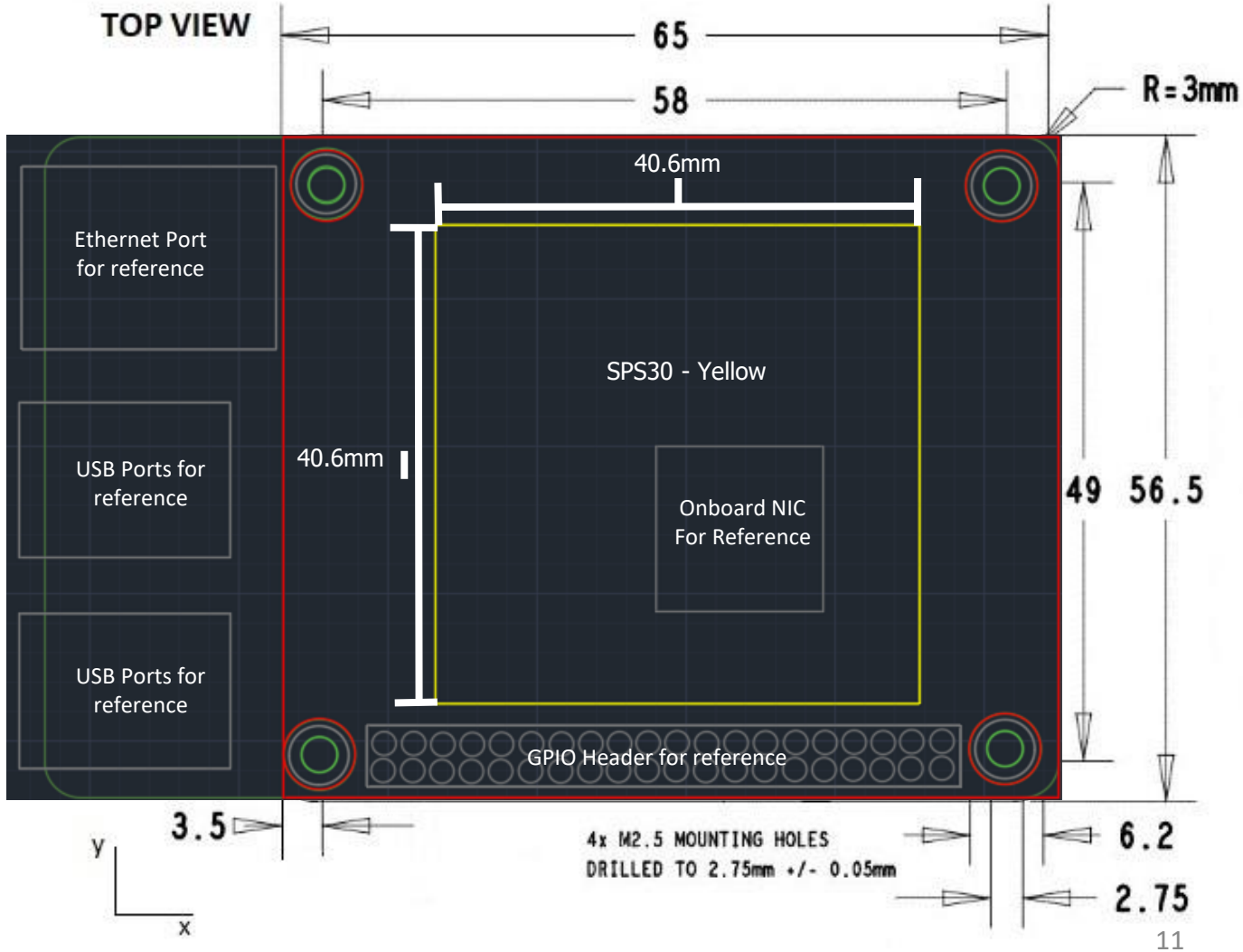
Phase 3
- Before AR2B end date, send last packet and poweroff.
- Analyze results.
- Write a report outlining findings.



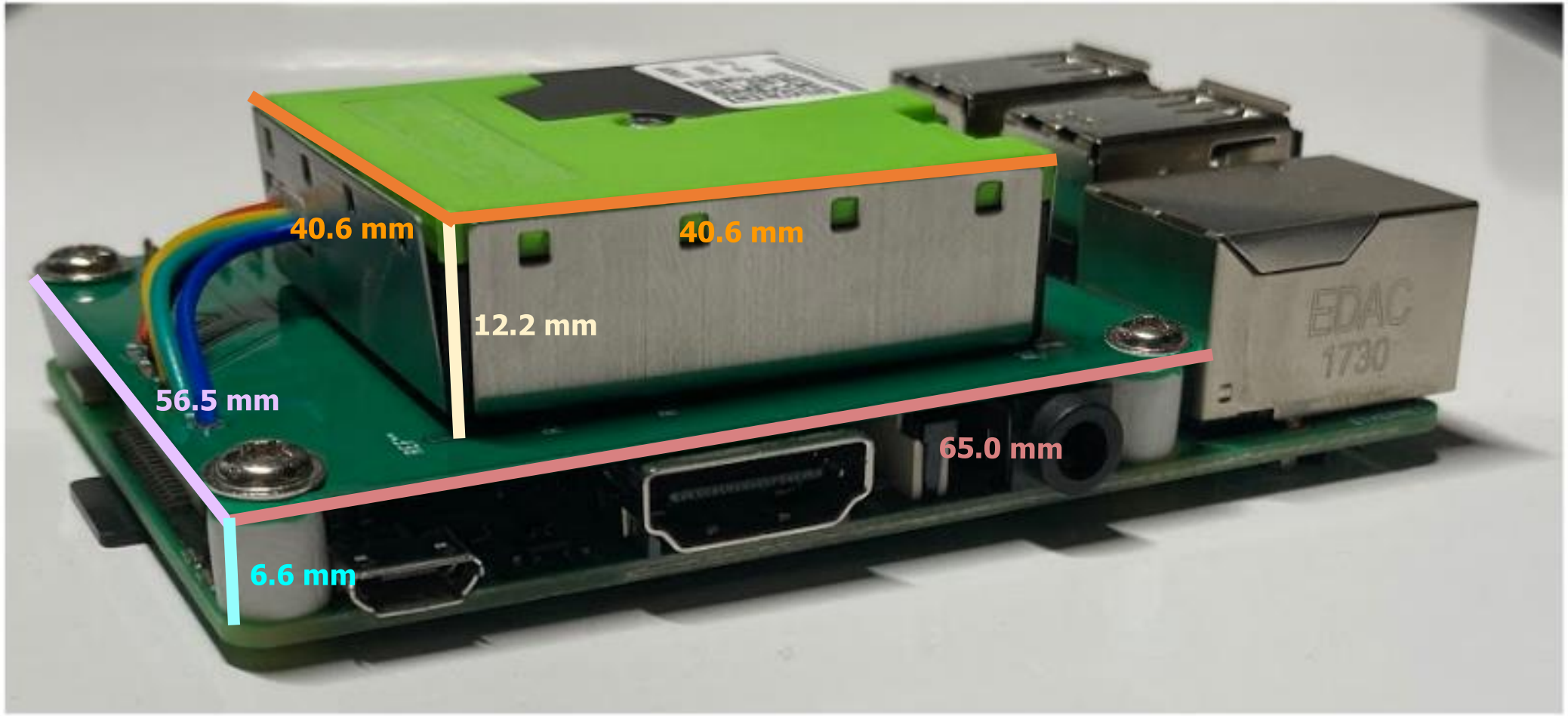
Experiment Configuration (cont.)

HAT Design (CAD)





Experiment Configuration (cont.)



Testing

Testable Requirements

Functional Requirements
Take Measurements
Organize Data Packets
Send Data
Establish Accurate Particulate Count
Handle Program Errors
Resume Operation After Reboot

Environmental Requirements
Survive Hot Environment
Survive Cold Environment
Survive Extreme Pressures
Survive Random Vibrations

Safety Plan

General Safety Practices

- Use proper Personal Protective Equipment (PPE).
- Have proper emergency equipment available.
- Ensure proper electrostatic discharge (ESD) protection.
- Use ground-fault circuit interrupter equipped (GFCI) outlets.
- Maintain clear and safe lab environment.
- Clean all equipment before and after use.

Hazard Avoidance

- Use N95-mask and fume hood to avoid possible inhalation of fumes.
- Verify equipment works before testing. (fume hood)
- Verify integrity and oil level of vacuum pump before and after use.
- Additional examples of hazard avoidance will be listed under the respective tests.

Functional Test - Recovery Test

Requirements

- UAH Requirements:
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Handle program errors.
  - Resume operation after reboot.

Test Environment and Reasoning

- Demonstrate that program can handle errors and resume operation at reboot.
- Errors tested: Unplugging SPS30 GPIO data wires, cycling power, killing programs, restarts, shutdowns
  - All program-triggered restarts are called by a monitor program

Results

- All programs worked as expected, experiment always started back up after reboot.
  - The monitor program was able to detect and recover from all conceived errors.
  - Test completed 50 times, 0 failures.

Evidence

- A picture of the populated /tmp/experiment directory after a run with the UAH program disabled.

Functional Test - Transfer Test

Requirements

- UAH Requirements:
  - Take measurements, organize data packets, and send data.
  - Data rate of less than **5.0** kBps.
  - Communicate with AR2B flight computer via /tmp/experiment/.

Test Environment and Reasoning

- Demonstrates that program can organize and send data packets.
  - Used UAH and team transfer programs.
- Verify data collected is organized and transferred to UAH's data handling program.
  - Test completed 25 times, 0 failures.
  - Pi was rebooted via various stimuli (see Recovery test).

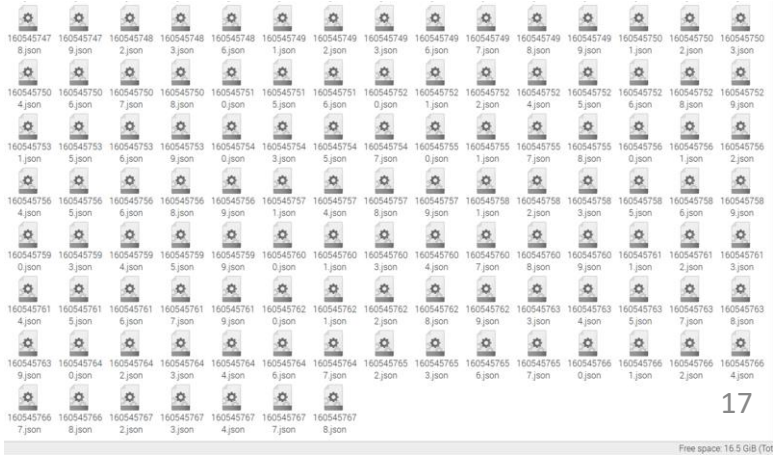
Results

- The programs all worked as expected, data was transferred in time stamped files to /tmp/experiment/ directory.
  - Max of 0.5 kBps, average of ~0.3 kBps
  - Example from UAH transfer program:

```
Out: 0.21KBps
```

Evidence

- A picture of the populated /tmp/experiment/ folder after a run with the UAH program disabled.



Functional Test - Sensor Test

Requirements

- UAH Requirements:
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Establish accurate particulate count.

Test Environment and Reasoning

- Verify sensor is accurate and functional.
  - Connected directly to GPIO header.
- Verify sensor can establish accurate particle counts.
  - Experiment placed in enclosed container and was run for 1 hour to establish baseline.
  - Butane lighter put in container for 5 seconds.
  - Lighter removed and container resealed.

Results

- The programs all worked as expected, data was collected with no errors.
  - No errors with I^2C connection.
  - Sensor detected particulates accurately.
  - Everything functioned as expected.

Evidence


```
"id": "PSA Team 1",
"pm0.5 count": "2.998706102371216",
"pm1": "0.43812096118927",
"pm2.5": "0.4889405369758606",
"pm4": "0.5096944570541382",
"pm10": "0.5138455629348755",
"pm_total": "(0.578999400138855,)"
```


Baseline Example Packet


```
"id": "PSA Team 1",
"pm0.5 count": "528.2876586914062",
"pm1": "75.61725616455078",
"pm2.5": "79.96244049072266",
"pm4": "79.96244049072266",
"pm10": "79.96244049072266",
"pm_total": "(0.5215598344802856,)"
```


Packet After Particulates Introduced

Vacuum Testing

Requirements to Meet

- UAH Requirements:
  - Survive vacuum.
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Survive vacuum for 30 minutes.
  - Meet all functional requirements.

Testing Environment/Plan

- Change oil and inspect vacuum chamber for defects
- Test each part of experiment (wires, board, SPS30) individually for 1 hour.
  - Follow steps in vacuum testing handout.
- Test assembled experiment with battery for 30 minutes.
- Allow repressurization of chamber, and remove experiment.

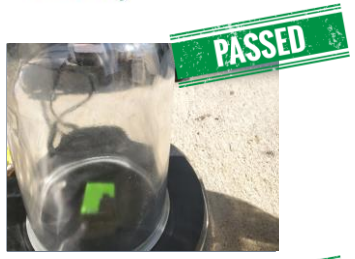
Personal Protective Equipment

- Clothing:
  - Lab Coat
  - Insulated Gloves
  - Safety Goggles
- Equipment:
  - Fire Extinguisher
  - GFCI protected outlet
  - ESD wristband (while handling pi)

Results

- Wires = Completed
- Board = Completed
- SPS30 = Completed
- Full Configuration = Completed
- More Details:
  - Sensor survived vacuum.
  - Sensor detects particles in vacuum.
  - Detected additional particles at intake.

Vacuum Test - Evidence/Results



Sensor Test

Wires Test

PCB Test

Full Configuration Test


Full Setup


Image from Outreach Video


```
"id": "PSA Team 1",
"pm0.5 count": "1.6045466661453247",
"pm1": "0.22966916859149933",
"pm2.5": "0.24286648631095886",
"pm4": "0.24286635220050812",
"pm10": "0.24286635220050812",
"pm_total": "(0.41308581829071045,)"
```

Baseline Packet 1


```
"id": "PSA Team 1",
"pm0.5 count": "1.3194762468338013",
"pm1": "0.18886524438858032",
"pm2.5": "0.19971798360347748",
"pm4": "0.19971798360347748",
"pm10": "0.19971798360347748",
"pm_total": "(0.3274580240249634,)"
```

Baseline Packet 2


```
"id": "PSA Team 1",
"pm0.5 count": "851.970947265625",
"pm1": "130.8596954345703",
"pm2.5": "164.066162109375",
"pm4": "184.85520935058594",
"pm10": "189.0128936767578",
"pm_total": "(0.31997978687286377,)"
```

Packet During Repressurization

Vacuum Test - Data Analysis

Data formatted in JSON Packets was generated by the experiment.

↓

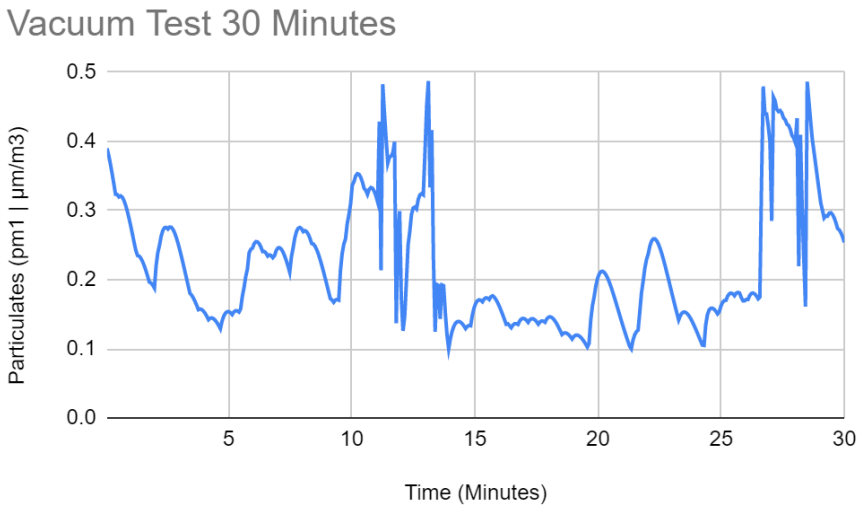
Data extracted with python program.

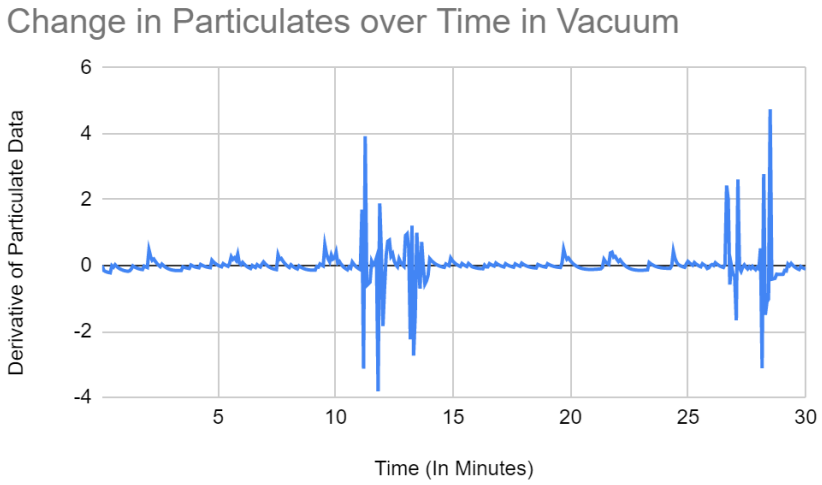
↓

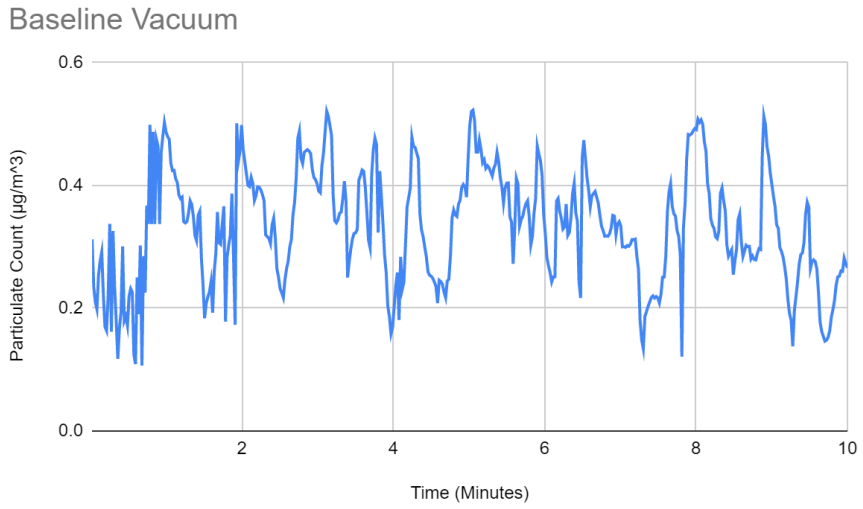
Data analyzed in Google Sheets for consistency and expected particulate detections.

↓

Regressions and other Statistical Analyses performed on data collected.







Heat Test

Requirements to Meet

- UAH Requirements:
  - Survive up to 90°C.
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Survive 90°C for 1 hour.
  - Meet all functional requirements.

Testing Environment/Plan

- Clean oven before test.
- Test each part of experiment (wires, board, SPS30) individually for 1 hour at 90°C.
- Preheat for 30 minutes for assembled test (90°C).
- Test assembled experiment at 90°C for 1 hour.
  - Power with external power source.
  - Verify functionality by introducing particle source.
- Allow to cool to 30°C before removing.

Personal Protective Equipment

- Clothing:
  - Lab Coat
  - Safety Goggles
  - Heat Resistant Gloves
- Other Equipment:
  - Fire Extinguisher
  - Fume Hood
  - ESD wristband (while handling pi)

Results

- Wires = Completed
- Board = Completed
- SPS30 = Completed
- Full Configuration = Completed
- More Details:
  - Use a container with particulates to verify functionality in heat.
  - Open ssh on pi for alternative to HDMI cable.

Heat Test - Evidence

Sensor Test

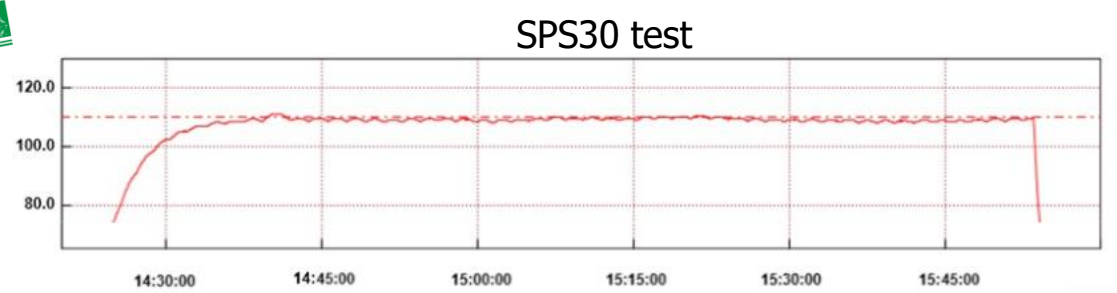
Wires Test

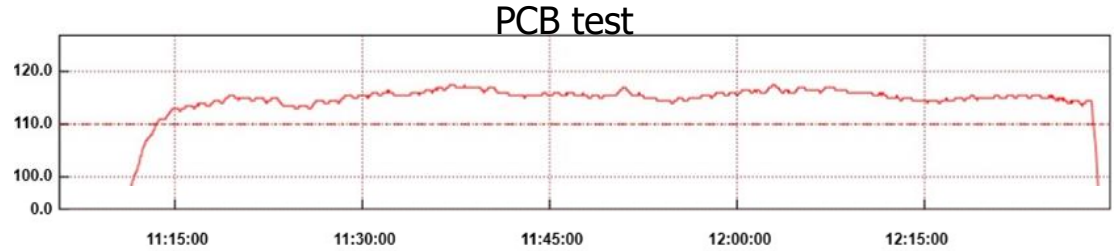
PCB Test

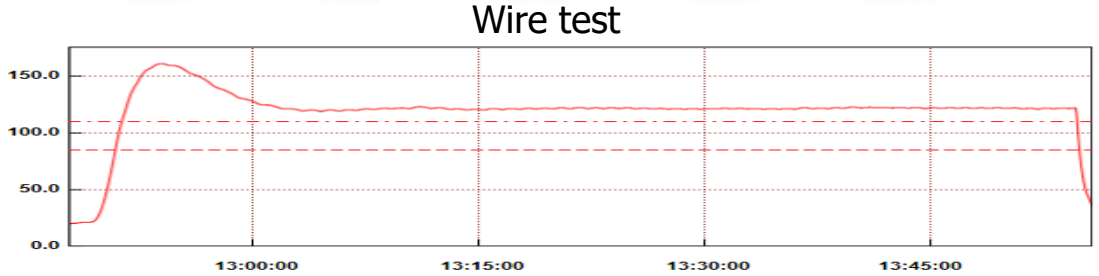
Full Configuration Test

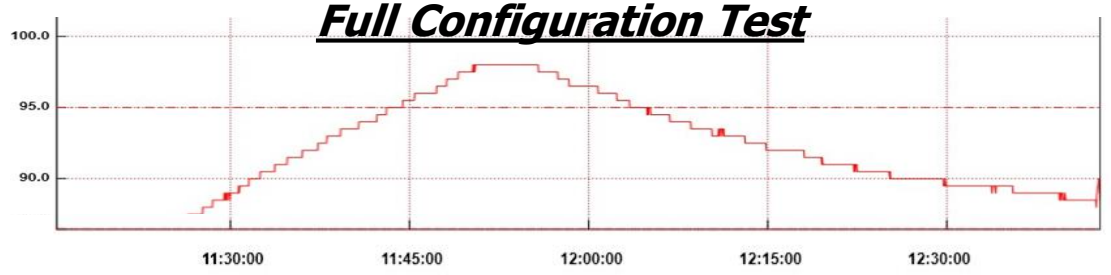

Samantha - Tester


Michael - Tester



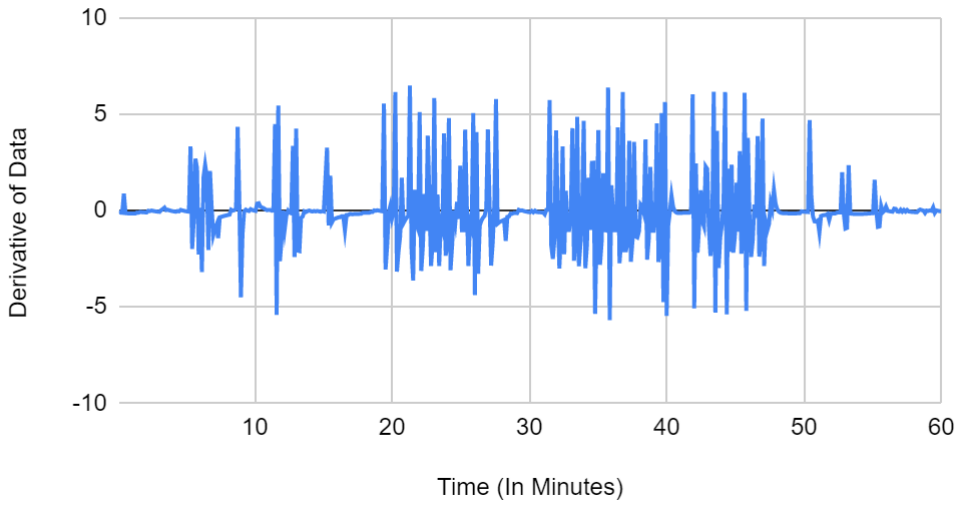




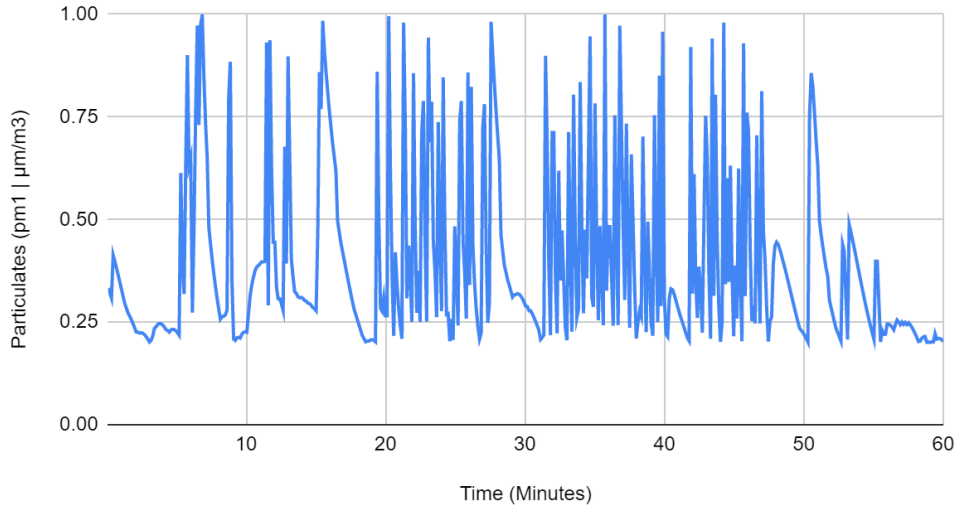


Heat Test - Data Analysis

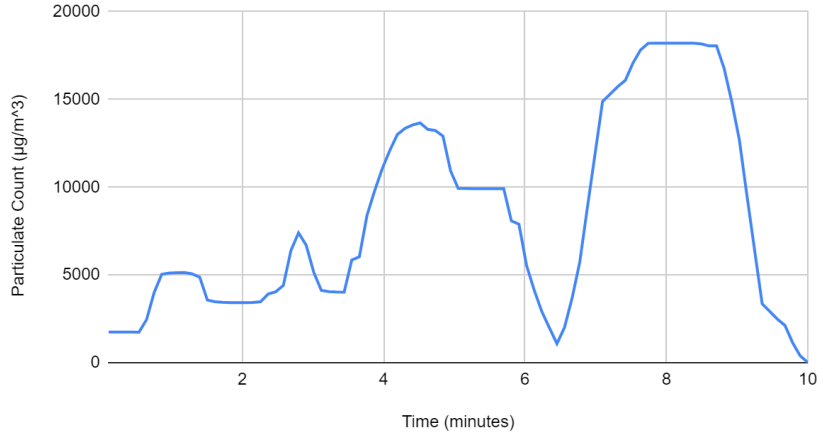
Change in Particulates over Time



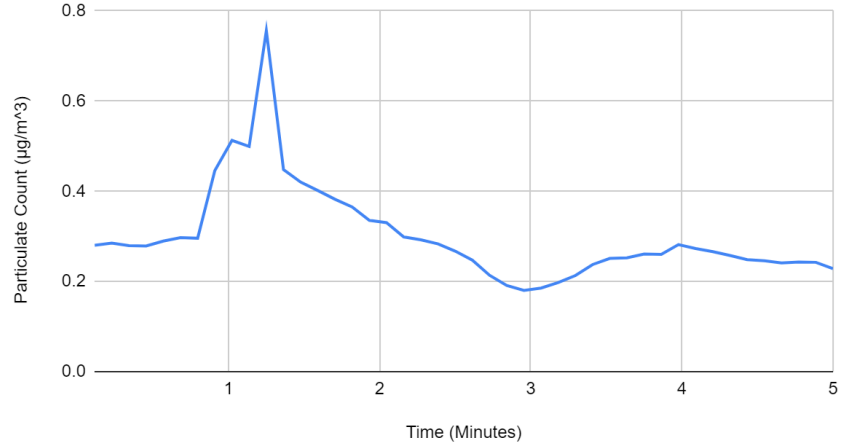
Heat Test 60 Minutes



10 Minute Particle Test



Baseline Heat Test 5 Minutes



Cold Test

Requirements to Meet

- UAH Requirements:
  - Survive temperatures as low as -20°C.
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Survive -20°C for 1 hour.

Testing Environment/Plan

- Set freezer to -20°C, allow 30 minutes to cool.
- Test each part of experiment (wires, board, SPS30) individually for 1 hour at -20°C.
- Test assembled operational experiment at -20°C for 1 hour.
  - introduce particulates using a sealable container.
- Remove using protective gloves.

Personal Protective Equipment

- Clothing
  - Lab Coat
  - Safety Goggles
  - Gloves
  - ESD wristband (while handling pi)

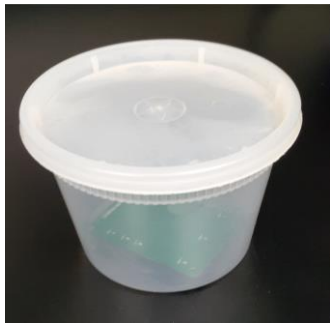
Results

- Wires = Completed
- Board = Completed
- SPS30 = Completed
- Full Configuration = Completed
- More Details:
  - The team ran a sensor test at -20°C, and the sensor was able to function accurately.

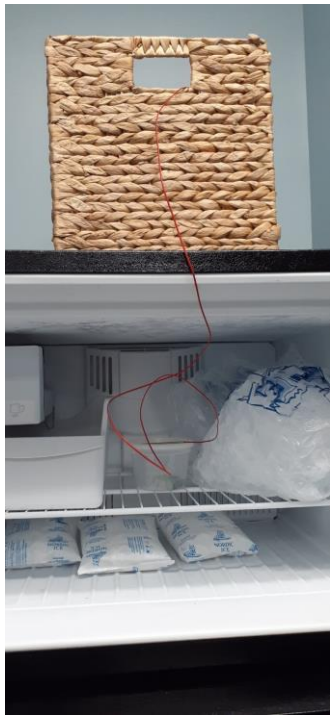
Cold Test - Evidence/Results

Wires

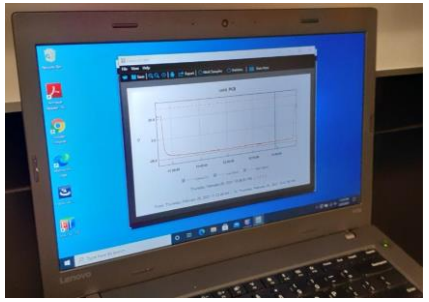
PCB



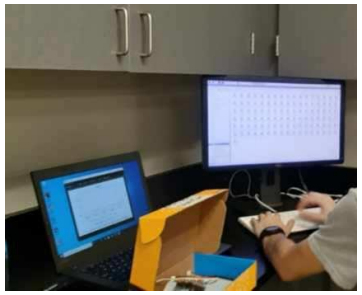
Test Configuration



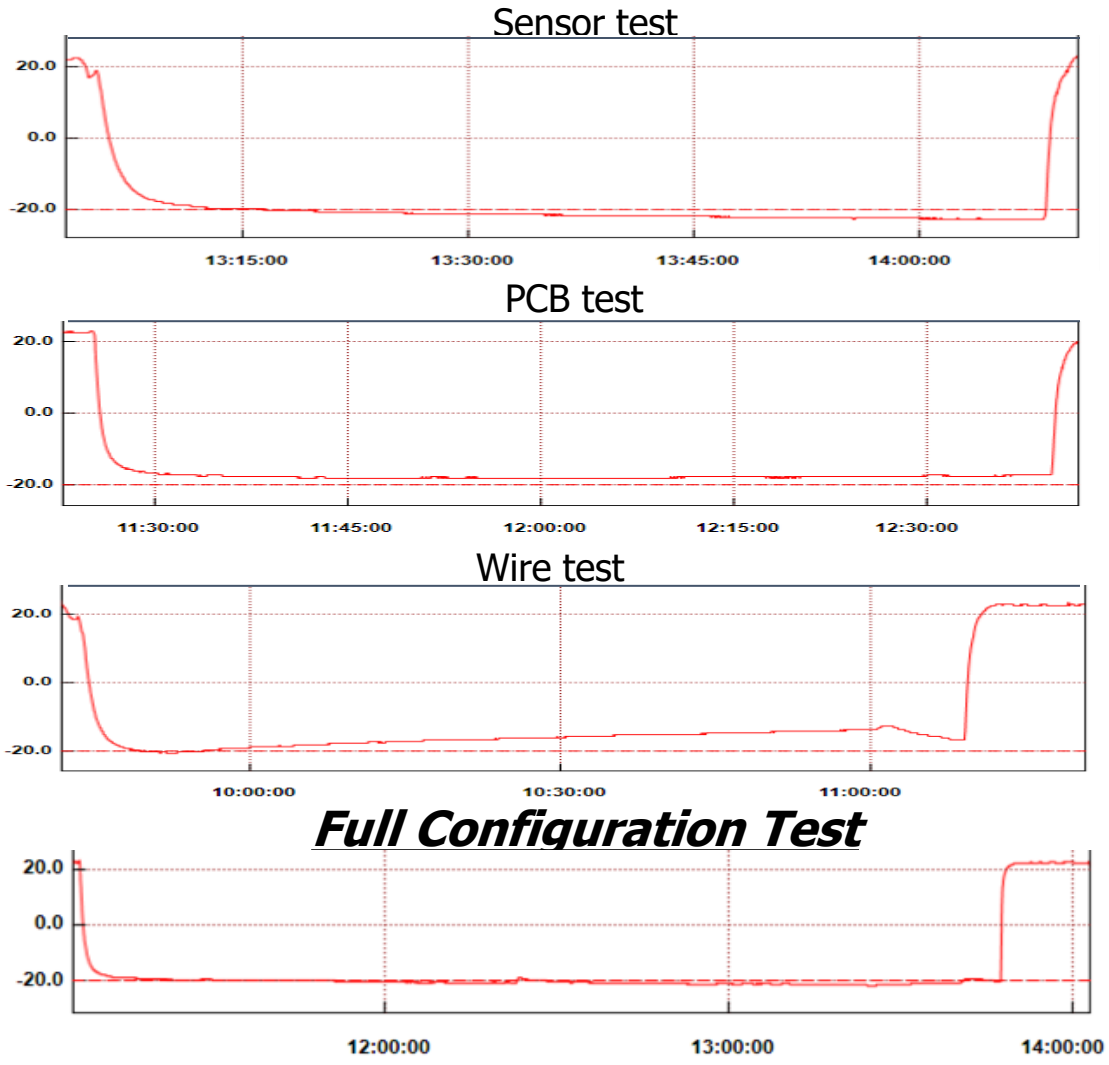
Test Configuration



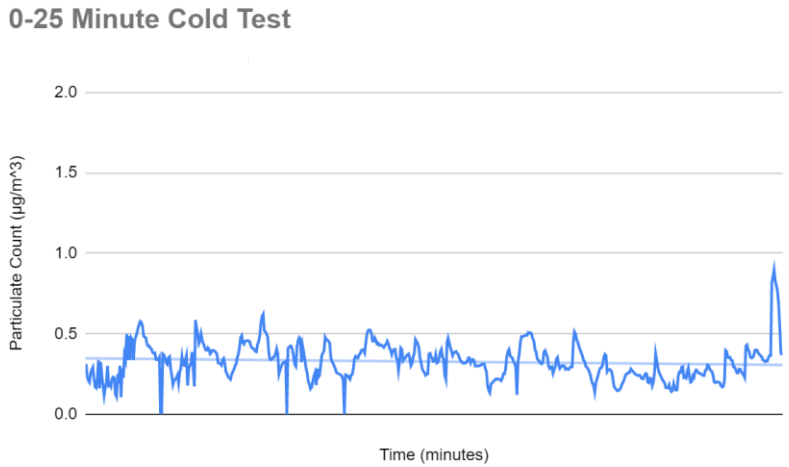
PCB Test Data

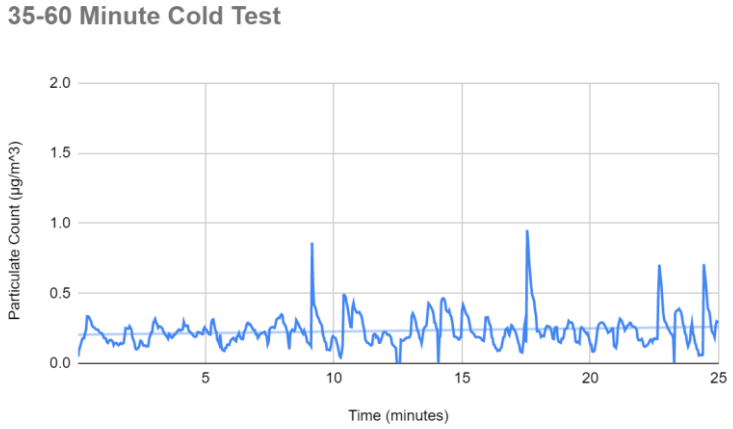


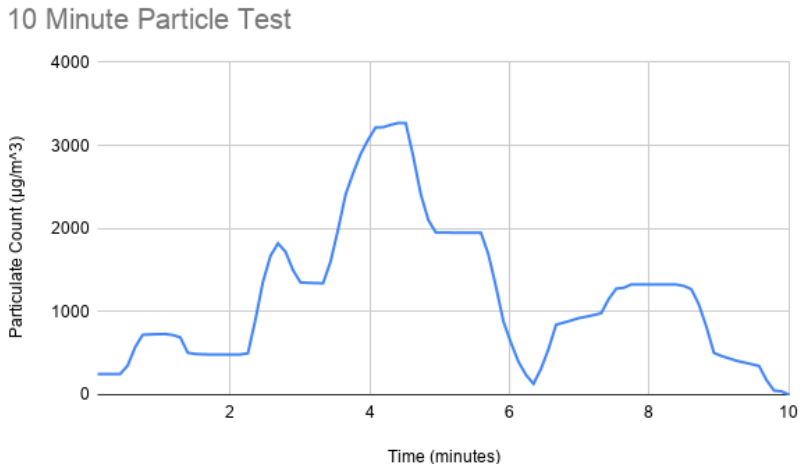
Picture Working

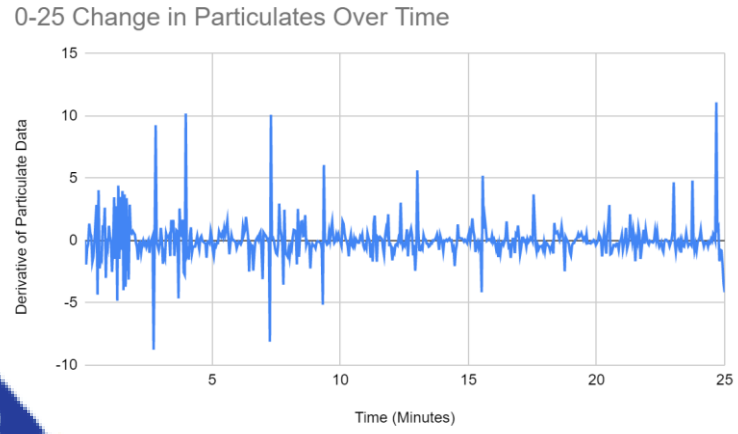


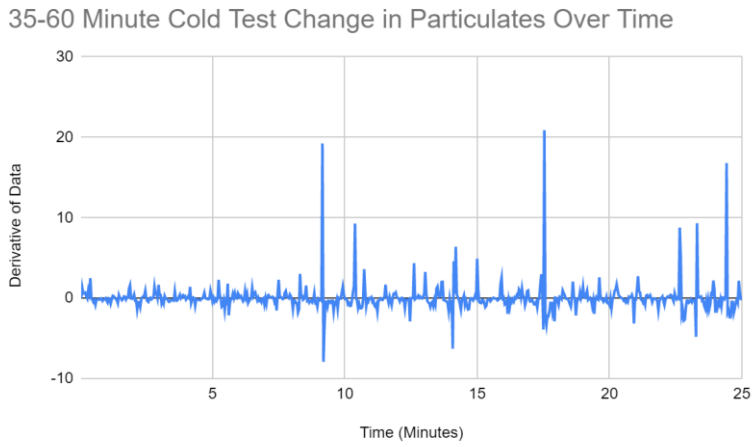
Cold Test - Data Analysis

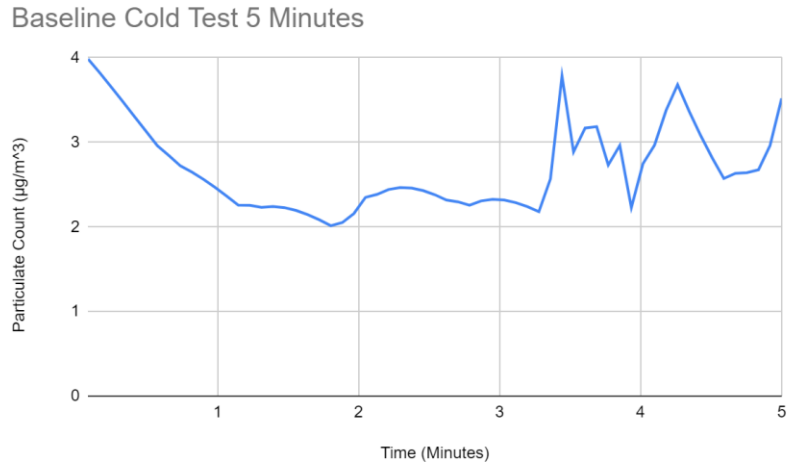












Random Vibration Testing

Requirements to Meet

- UAH Requirements:
  - Survive random vibrations up to 4 gs.
  - Take measurements, organize data packets, and send data.
- Team Requirements:
  - Survive 4 gs for 15 minutes.

Testing Environment/Plan

- Check integrity of parts beforehand
- Use dampeners and rubber mallet to create random acceleration.
  - Follow Vibration testing handout.
  - Mount experiment to wood.
  - Connect accelerometer to computer with usb extension cable.
  - Inspect for damage after test.

Personal Protective Equipment

- Clothing
  - Lab Coat (while in lab)
  - Gloves (while handling pi)
  - ESD wristband (while handling pi)

Results

- Full Configuration Test = Completed
- More Details:
  - Be extra cautious with experiment while not in lab environment.
  - Hit wood into foam eggcrate at different angles.
  - Be careful not to hit fingers.

Vibration Test - Evidence/Results

Max X	6377 12/4/2021 21:59:42	Min	-6503 12/4/2021 21:59:42	Average	-803	X Threshold	15	Start Time	12/4/21 21:59:38
Max Y	7965 12/4/2021 21:59:43	Min	-7107 12/4/2021 21:59:42	Average	872	Y Threshold	14	Samping rate	100 millisecond
Max Z	8765 12/4/2021 21:59:42	Min	-6440 12/4/2021 21:59:43	Average	1295	Z Threshold	13	Samples	9283

Accelerometer Data

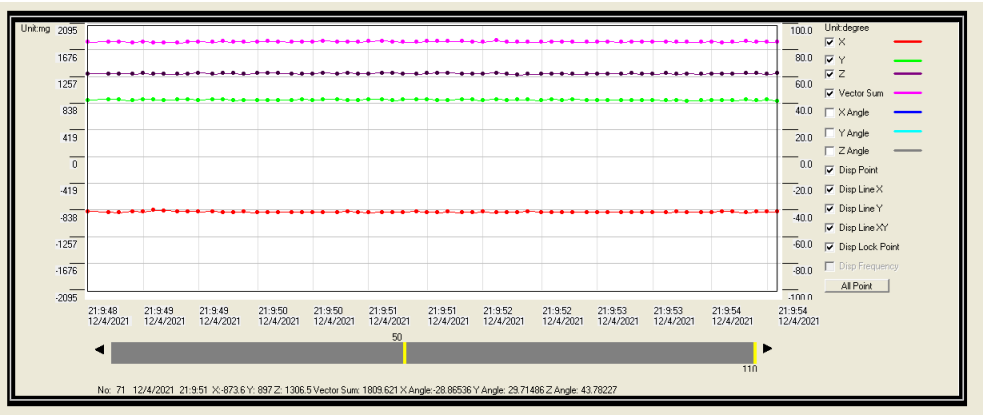
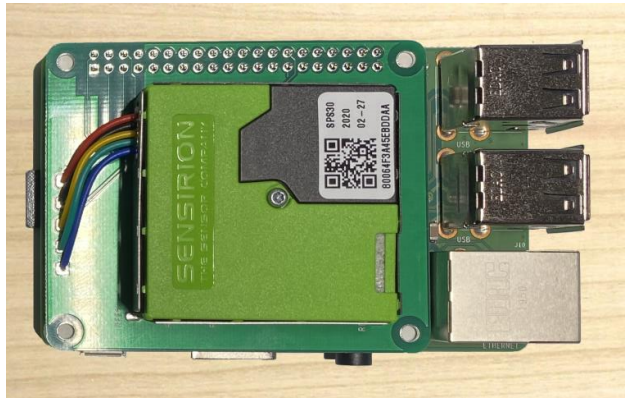


Photo of Accelerometer Software

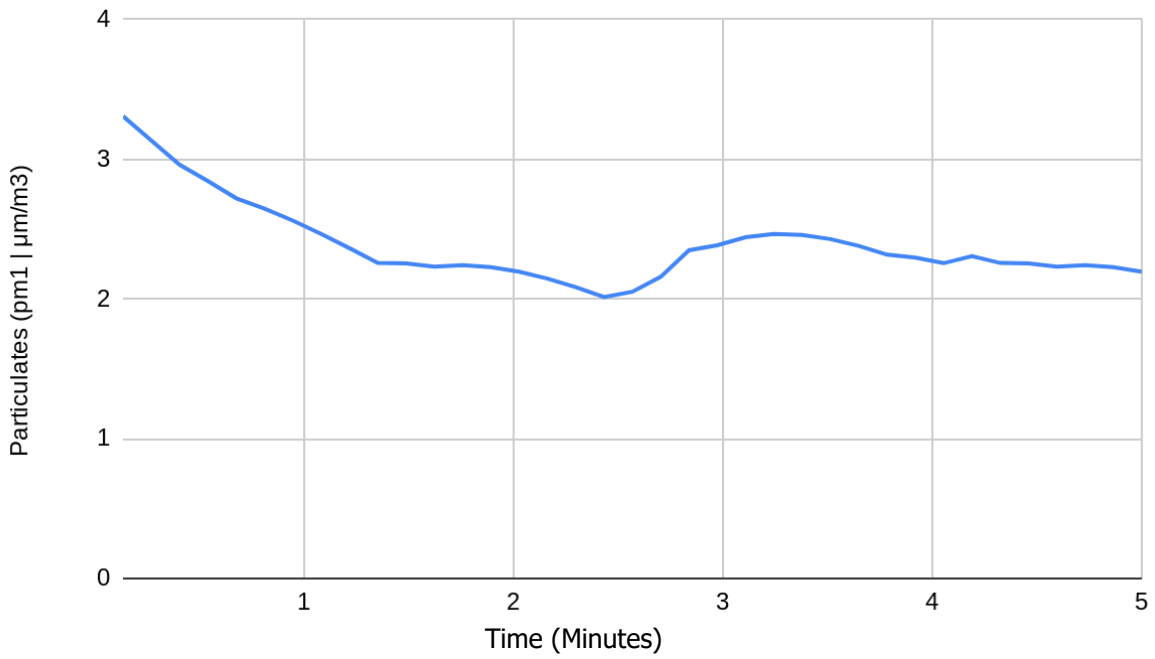


Experiment on Wood

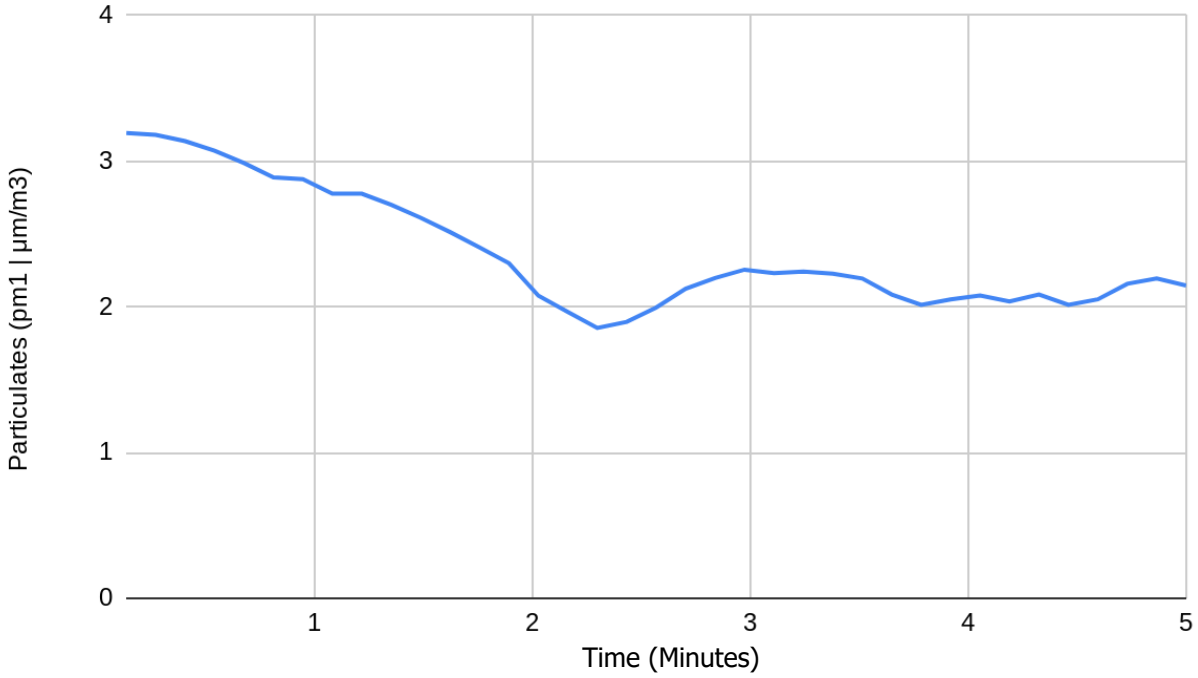
	Calibration Value	Math	G
X-Axis	-877 mg	877 + 6377 6503 - 877	7.254 5.626
Y-Axis	884 mg	-884 + 7965 884 + 7107	7.081 7.991
Z-Axis	1305 mg	-1035 + 8765 1035 + 6440	7.730 7.475

Vibration Test - Data Analysis

5 Minute Baseline



5 Minute Baseline (After Vibration test)



Requirements Compliance

Requirement	Verification	Compliance
Take Measurements	Functionally tested with the sensor test.	✓
	Tested Pi HAT measurement capabilities in different environmental conditions	✓
Organize Data Packets	Functionally tested with transfer test.	✓
Send Packets	Tested the data transfer via the transfer test.	✓
Establish Accurate particulate count	Functionally tested the particulate matter sensor via environmental and sensor tests.	✓
Handle Program Errors	Functionally tested with the recovery test.	✓
Resume operation after reboot	Functionally tested with the recovery test.	✓

Requirements Compliance (cont.)

Requirement	Verification	Compliance
Survive hot temperatures (Survive 90C for 1 Hour)	Experiment passed Heat Test by operating at 90C for 1 hour.	✓
Survive cold temperatures (Survive -20C for 1 Hour)	Experiment passed Cold Test by operating at -20C for 1 hour.	✓
Survive extreme pressure (Survived vacuum for 30 minutes)	Experiment passed Vacuum Test by operating in a vacuum for 30 minutes.	✓
Survive Random Vibrations (Survived 4g of Vibration for 15 minutes)	Experiment passed Vibration test by surviving 4 g of random vibration for 15 minutes.	✓

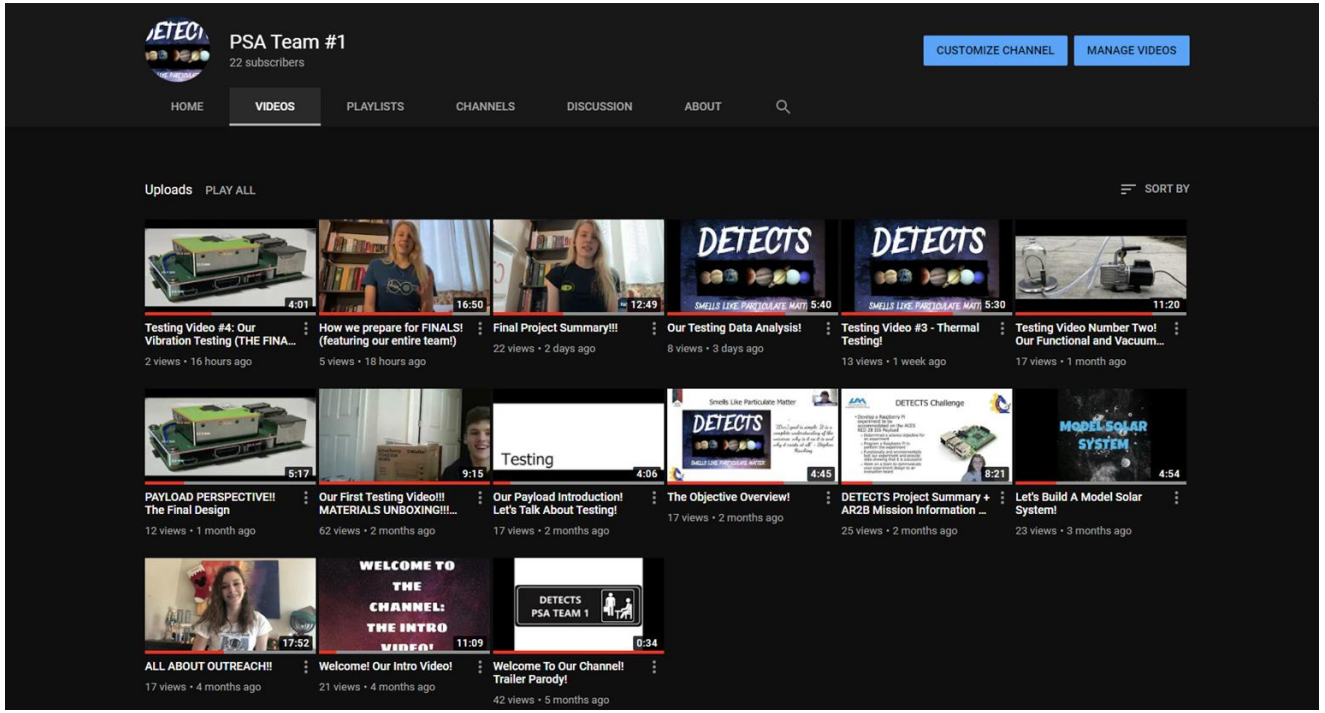
ICD Compliance

Requirement	Verification	Compliance
No larger than **65 x 56.5 x 19 mm**	Experiment dimensions of 65 x 56.5 x 18.8 mm	✓
Securely mounted to the Pi	Survived 4g of random vibrations (verified by Vacuum test)	✓
Interfaces with the 40-pin GPIO header on a Raspberry Pi 3B+	Uses Pi HAT to interface with the 40-pin GPIO	✓
5 kilobytes per second or smaller data rate	0.5kBps data rate verified with the Transfer Test	✓
JSON formatted data packets delivered to the */tmp/experiment/* folder	Successful packet transfer verified with Transfer Test	✓
No potential harm to AR2B mission	Meets All Requirements set forth by AR2B	✓

Online Outreach

Outreach Plan

Our goal, as a team, is to create an online presence to engage and inform viewers about DETECTS and our team. This will be done by sharing both informative and fun videos on our main platform Youtube.

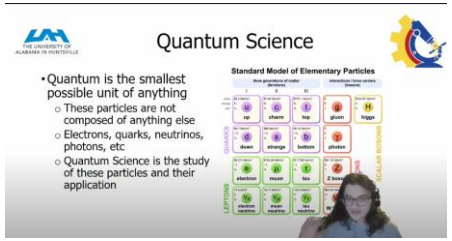


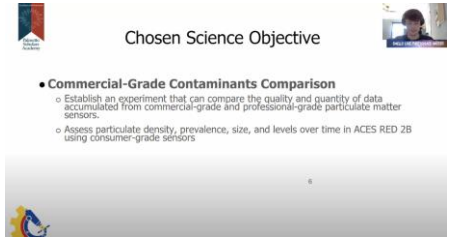
Our platform choice was based on our contents topic, targeted demographic, team dynamic, ability to have creative freedom, and the popularity of the platform.

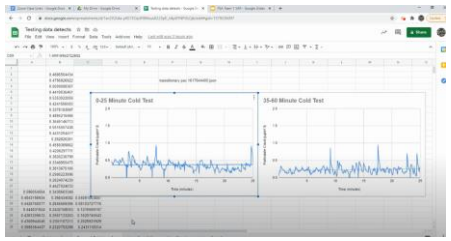
Outreach Videos

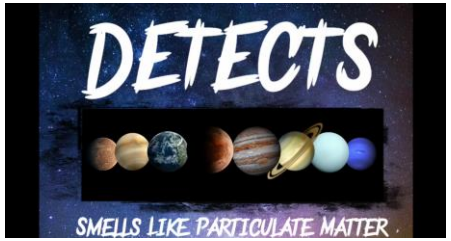
- "Welcome To Our Channel" Trailer
- "Our Introduction Video"
- "All About Outreach!"
- "Let's Build A Model Solar System!"
- "DETECTS Project Summary + AR2B Mission Information"
- "The Objective Overview"
- "Our Payload Introduction! Let's Talk About Testing"
- "Our First Unboxing Video! MATERIALS UNBOXING!"
- "Payload Perspective! The Final Design"
- "Testing Video #2: Our Functional and Vacuum Testing"
- "Testing Video #3: Thermal Testing!"
- "Our Testing Data Analysis!"
- "Final Project Summary!"
- "How We Prepare For Finals!"
- "Testing Video #4: Vibration Testing"
- "Pros & Cons + The Lessons We Learned Along The Way"
- "Thank You"

Outreach Videos

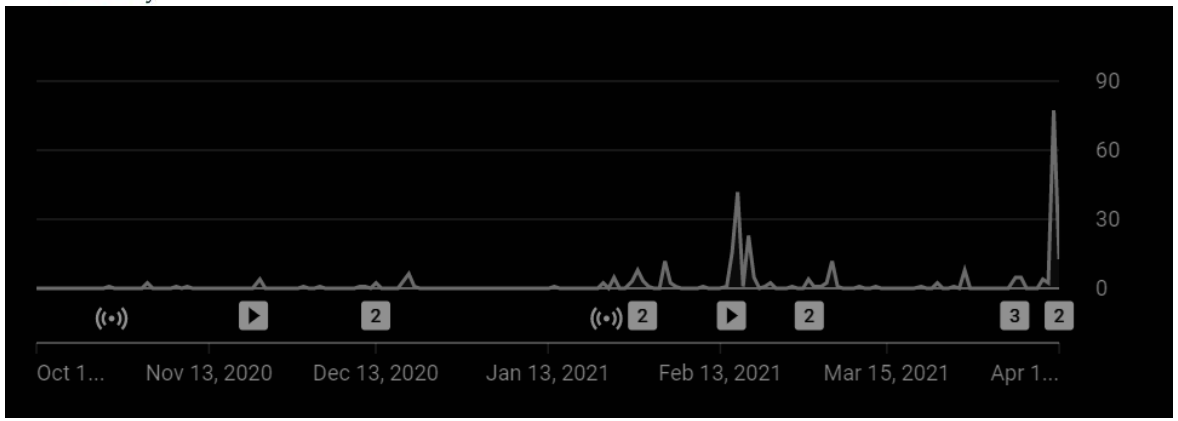




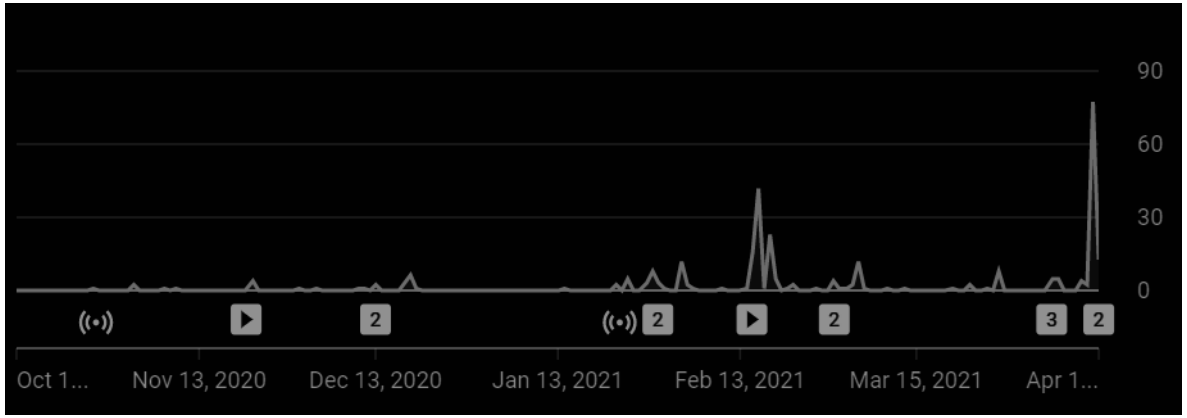




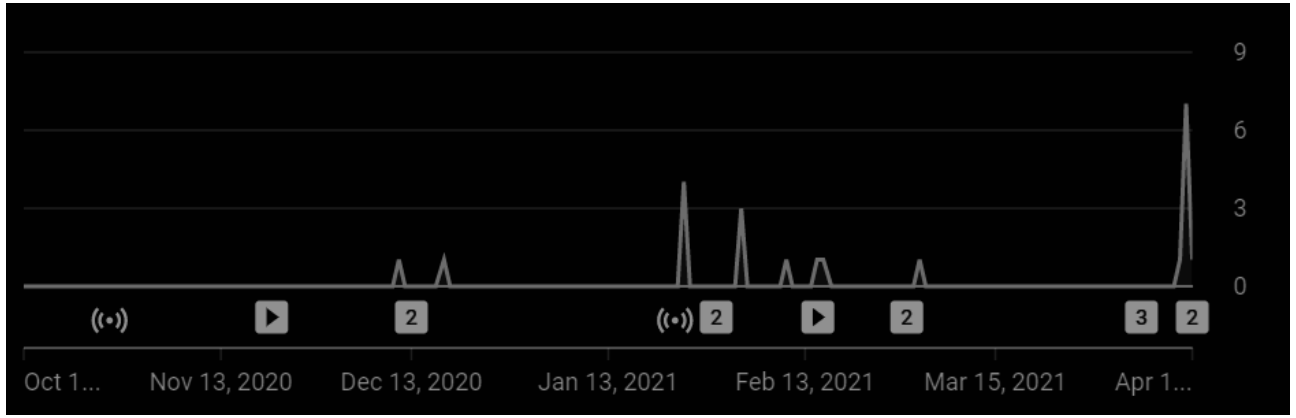
Outreach Platform Analysis



Views On The Team's Channel From October 13th - April 16th



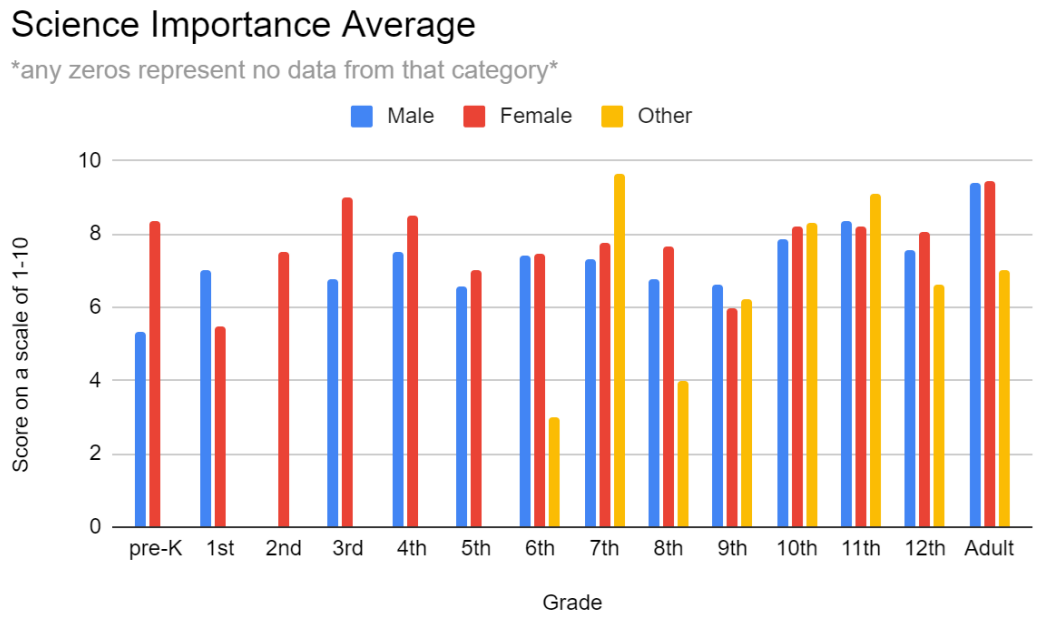
View Time (In Hours) Of The Channel's Videos



Subscriber Count For The Team's Channel

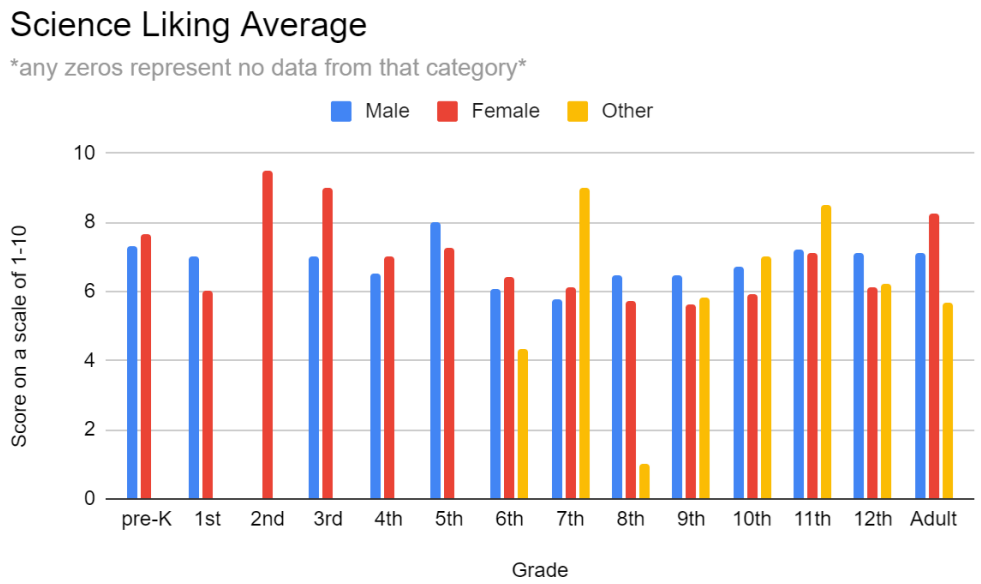
Survey Analysis

Science Importance														
	pre-K	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Adult
Male	5.333	7	0	6.75	7.5	6.555	7.393	7.31	6.777	6.597	7.88	8.361	7.58	9.38
Female	8.333	5.5	7.5	9	8.5	7	7.454	7.742	7.648	5.96	8.192	8.186	8.062	9.461
Other	0	0	0	0	0	0	3	9.666	4	6.2	8.3	9.083	6.6	7



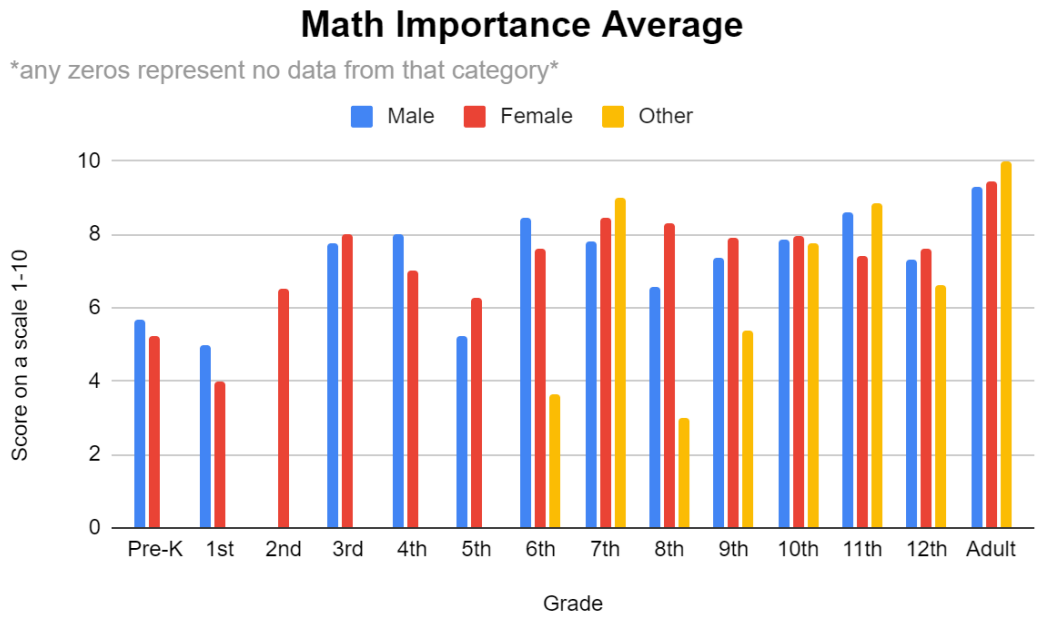
Survey Analysis

Science Liking														
	pre-K	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Adult
Male	7.333	7	0	7	6.5	8	6.09	5.793	6.444	6.489	6.693	7.191	7.1	7.129
Female	7.666	6	9.5	9	7	7.25	6.424	6.142	5.729	5.637	5.923	7.093	6.125	8.265
Other	0	0	0	0	0	0	4.333	9	1	5.8	7	8.5	6.2	5.666



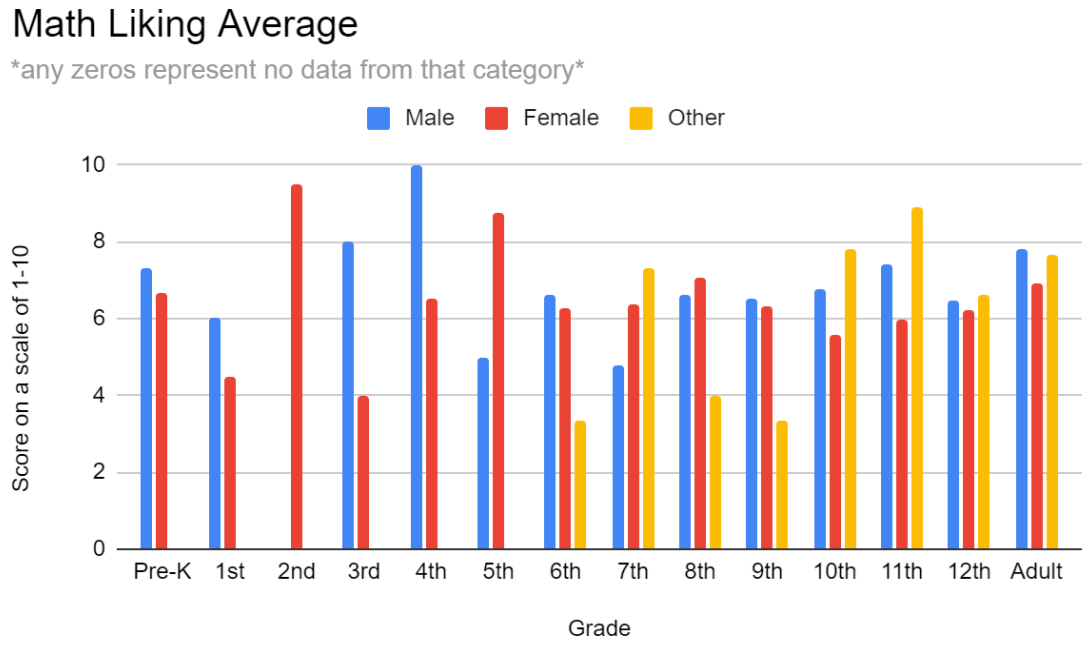
Survey Analysis

Math Importance	Pre-K	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Adult
Male	5.666	5	0	7.75	8	5.222	8.459	7.793	6.576	7.382	7.88	8.625	7.322	9.283
Female	5.25	4	6.5	8	7	6.25	7.62	8.428	8.289	7.904	7.935	7.391	7.625	9.422
Other	0	0	0	0	0	0	3.666	9	3	5.4	7.777	8.833	6.6	10



Survey Analysis

Math Liking	Pre-K	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Adult
Male	7.333	6	0	8	10	5	6.636	4.758	6.629	6.5	6.746	7.391	6.483	7.788
Female	6.666	4.5	9.5	4	6.5	8.75	6.281	6.352	7.054	6.32	5.564	5.956	6.2	6.93
Other	0	0	0	0	0	0	3.333	7.333	4	3.333	7.8	8.9	6.6	7.666



Summary

Lessons Learned

Leadership	Experiment Group	Testing Group	Outreach Group
Learned: Organizational Skills Time Management	Learned: Collaborate Online Enhance Productivity	Learned: Better Communication Importance of Scheduling	Learned: Operate Online Platforms Online Outreach
Problems: Miscommunications early in the semester	Problems: Remote Programming PCB Design	Problems: Remote Testing	Problems: Managing multiple platforms
Future: Work Independently Use Class Time to Collaborate	Future: Programming in Person New program proficiency	Future: Planned testing dates and scheduled Zoom calls	Future: Collaborate with established platforms. Reach out to students at PSA through teachers

Summary

Design Summary

- Science Objectives:
  - Assess particulate density, prevalence, size, and levels over time
  - Compare to currently used particulate sensing equipment
- Configuration
  - Instruments: SPS30 Particulate Matter Sensor
  - PCB is 65 x 56.5 x 0.6mm
  - 65 x 56.5 x 18.8mm
  - Outputs ~0.3 kBps normally, max 0.5 kBps
- 6 Major Program Parts
  - Startup, Control, Transfer, Monitor, UAH's Data Send, and Restart

Outreach

- 1,032 Survey Collected
- Youtube - Major Platform
  - 17 videos

Testing

- Functional Testing and Requirements
  - Sensor - Can detect particulate matter accurately ✓
  - Transfer - Max data rate of 0.5kBps ✓
  - Recovery - Experiment recovered from all conceived scenarios ✓
- Environmental Testing and Requirements
  - Vacuum - Operated in vacuum-like conditions for 30 minutes. ✓
  - Heat - Operated in temperatures up to 90°C for 1 hour. ✓
  - Cold - Operated in temperatures down to-20°C for 1 hour. ✓
  - Vibrational - Survived random vibrations up to 4gs for 15 minutes. ✓

Requirement	Verification	Compliance
No larger than **65 x 56.5 x 19 mm**	Payload Dimensions of 65 x 56.5 x 18.2 mm	✓
Securely mounted to the Pi	Survived 4g of random vibrations (verified by Vacuum test)	✓
Interfaces with the 40-pin GPIO header on a Raspberry Pi 3B+	Uses Pi HAT to interface with the 40-pin GPIO	✓
5 kilobytes per second or smaller data rate	0.5kBps data rate verified with the Transfer Test	✓
JSON formatted data packets delivered to the */tmp/experiment/* folder	Successful packet transfer verified with Transfer Test	✓
No potential harm to AR2B mission	Meets All Requirements set forth by AR2B	✓