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GIFTS: Course-based Undergraduate Research Experience in a First-Year Design Course

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GIFTS: Course-based Undergraduate Research Experience in a First-Year Design Course

Fayekah Assanah, Britney Russell, Marina Creed, Misti Zamora, Kristina Wagstrom

Motivation

This Great Ideas for Teaching Students (GIFTS) paper presents a guided project to engage first-year engineering students in research through a "Course-based Undergraduate Research experience. Undergraduate research enables students to apply classroom concepts to research concepts in the real world. First-year students can benefit from a structured introduction to research practices and contribute to research projects in the future [1]. This GIFTS paper describes a short-term service-learning project with a research-based lesson plan where students develop proficiency in Excel, follow experimental protocols to collect data, and then apply data analysis skills to answer a real-life research study question (all within a classroom setting). 400 first-year students across multiple engineering disciplines, at the University of Connecticut, engaged in a service-learning project to build and test a cost-effective do-it-yourself (DIY) air purifier (also called a Corsi-Rosenthal (C-R) Box). The C-R Box reduces respiratory aerosols and improves indoor air quality. Prior to the project, students completed an in-class Excel workshop to practice processing and plotting data using a sample data set. Students then worked in teams of four in the First-Year Design Laboratory for two weeks to build and test these air purifiers [2,3]. After building the C-R boxes, students performed a two-hour test to evaluate the efficiency of their air purifiers in reducing indoor particulate matter levels following a detailed experimental protocol. Using the knowledge gained in the Excel workshop, students analyzed and plotted the collected data as part of the assessment. The combined data collected by the student teams are included in a publication currently under preparation. This "research-integrated" project exposed first-year students to real-life research early in the undergraduate curriculum and demonstrated how scientific inquiry can be integrated into a first-year engineering course through a simple project.

The First-Year Engineering Course and the Corsi-Rosenthal (C-R) Box Project

We implemented this GIFTS Course-based Research Project in the Foundations of Engineering (ENGR 1166) course at the University of Connecticut during the spring semester. The required first-year course enrolls over 400 students and includes three concurrent components: (a) lecture (introduces key engineering concepts), (b) major-specific content (MSC) (teaches discipline-focused problem solving), and (c) project-based design labs. We embedded the lesson plan for this GIFTS project into the design lab curriculum (sections of ~30 students) as part of a short-term, project-based service learning (PBSL) activity [2, 3] at the beginning of the semester. The C-R box is a do-it-yourself, portable air purifier that traps ~60% of indoor air particles, improving indoor air quality and mitigating disease transmission, such as respiratory syncytial virus (RSV) and influenza (primarily spread through respiratory aerosols from infected individuals) [4, 5, 6]. The C-R box project is an effective PBSL, previously described as a work-in-progress and as a GIFTS paper, in which students built these air purifiers using low-cost materials. Students participated in the PBSL activity for three consecutive years, resulting in over 1200 participants. During the third iteration of this PBSL, we added a research component in which students not only built the C-R boxes but also collected and plotted real-time data on the performance of their air purifiers in reducing the indoor particulate matter levels during a two-hour lab session. We are currently compiling the testing and evaluation conducted by all teams for a publication evaluating the consistency of performance across do-it-yourself air purifiers. This opportunity provided an excellent platform to evaluate the performance differences that may arise from small variations in assembly and from underlying supplies for 100 purifiers built by 100 different student teams.

Objectives of the Course-based Research Project and Learning Outcomes

The learning outcomes (LOs) for ENGR 1166 are the ABET outcomes (2024): LO1) fundamental problems and critical thinking, LO2) iterative design, LO3) multidisciplinary teamwork, LO4) effective communication, and LO5) ethics. This GIFTS Project covered LO1 - LO5. Through the guided lesson plans for this project, students learned about the concerns of indoor air pollution and the mitigation strategies in the real world (LO1). They also completed a comprehensive workshop on importing datasets and plotting graphs in Excel (LO1, LO4). Students worked in teams of four (self-chosen) to build the C-R boxes and suggested design improvements at the end of the build (LO2, LO3, LO4). This PBSL then extended into the Course-based Research Project, where students collected and plotted the data for particulate matter reduction in real-time data using Excel to determine the efficacy of the C-R boxes (LO1, LO4, LO5).

Implementation Guidelines

Table 1. The activities included in the course each week. Details are included in Appendix 1.

Number of Weeks	**Activity**	**Objective**
Week 1 (Excel Workshop)	Learn and practice data plotting for a sample data set in Excel.	LO1: fundamental concepts/critical thinking, LO4: communication
Week 2 (Construction)	Students built C-R boxes in teams through guided lesson plans. Students performed a quality control check and peer inspection. (Appendix 1)	LO1: fundamental concepts/critical thinking, LO2: design, LO3: teamwork, LO4: communication
Week 3 (Testing)	Students tested the C-R boxes for the particulate matter (PM) reduction following an experimental protocol. (Appendix 1). Students used their collected data to plot scatter plots using Excel, calculated the Air Changes per Hour (ACH), and Clean Air Delivery Rates (CADR). (Appendix 1)	LO1: fundamental concepts/critical thinking, LO4: communication, LO5: ethics

As part of the design lab curriculum, students completed a comprehensive "Excel Module" during the first week of class. In this module, students installed Excel and learned about various plotting functions. Students then imported an example dataset (for reduction in particulate matter (PM) with air purifier) and gained practice in plotting and improving the data visuals. The next two weeks in the course marked the PBSL project, during which students worked in groups of 4-5 to construct C-R boxes using a single 10" fan and five 12" MERV-13 filters [2, 3]. A total of 100 teams successfully built and evaluated the build quality of the C-R boxes (Details about how to build the box is in Appendix I).

During the second week of the PBSL, the course instructors and teaching assistants set up six individual testing rooms for data collection of PM. Each room was equipped with a humidifier, an air-quality monitor, and a designated spot for the students to place their C-R boxes. The volume of each room was measured and provided to the student teams. The lesson plans (supplemented by a video tutorial) provided step-by-step protocol for setting up and collecting the PM data. During the lab sessions, students followed that protocol to activate the C-R boxes after humidifier operation and collect the data on particulate matter reduction (in real-time) for approximately two hours. Students started the test by using an ultrasonic humidifier filled with a dilute salt solution to create a high particle count in the room. After five minutes, the humidifier was turned off, and the air purifier was turned on. The concentration of particles in the room was then monitored using a QuantAQ MODULAIR^{TM}-PM air monitor. Data was recorded automatically on SD cards on the air-quality monitor system. Teaching assistants facilitated data retrieval.

The approach for estimating Clean Air Delivery Rate (CADR) (a measure of the rate the purifier is producing clean air) used for these experiments follows Jehn et al.'s work. [7]. CADR is an important parameter used by researchers and industry to determine the effectiveness of air purifiers. Overall, this approach uses the fact that the decrease in particles in a room both with and without an air purifier follows a first-order decay (Figure 1). One of the teaching assistants ran the tests for the background decay (and air changes per hour) for each room. Students plotted the ln(concentration) vs time, which gave a linear relationship graph in Excel, allowing them to calculate the CADR for their specific air purifier, The students then used the difference between the Air Changes per Hour without the purifier and that with the humidifier and the volume of the room to calculate the CADR. These calculations are detailed in the Appendix 1, Lesson Plan – Week 2. Through this activity, students validated the efficacy of C-R boxes in purifying indoor air by reducing particulate matter concentrations, thus enhancing the overall air quality of their classrooms.

Assessments

Student teams submitted Engineering Logs and Portfolios as part of the lab assignments. They documented the building, quality control, and testing processes for the C-R boxes, detailed teamwork and task division (via Gantt charts), and suggested design improvements. Students also plotted scatter plots of the data they collected from their experiments using Excel. Logs also included reflections on testing methods and ethical considerations, and students received feedback from instructors and TAs.

Results and Conclusion

All the teams successfully built and tested the C-R boxes. At the end of the project, all C-R boxes were donated to Connecticut Veterans for migraine study. The results of how the students achieved the LOs of this project are previously described in [2,3]. Figure 1 shows this first-order decay of the concentration of the PM across all tests and all testing rooms. The consistency between the decay findings across tests highlights how well students were able to follow the given experimental protocol. The negative slope of the ln(concentration) vs time plot is the Effective Air Changes per Hour [units = rooms/time], a measure of how rapidly the air in the room is replaced with clean air.

The full analysis of the data collected by students is not included here as it is in preparation for a peer-reviewed publication. Students submitted the calculations done above as part of their engineering logs to demonstrate how they 1) built the CR-Boxes, 2) quality controlled the purifiers 3) collected and analyzed data in Excel. This demonstrates the scope and goal of this Course-based Research Project: that students are able to build a small project in the lab, test it in real-life situations, and therefore take part in answering the research question about the efficacy of the purifier.

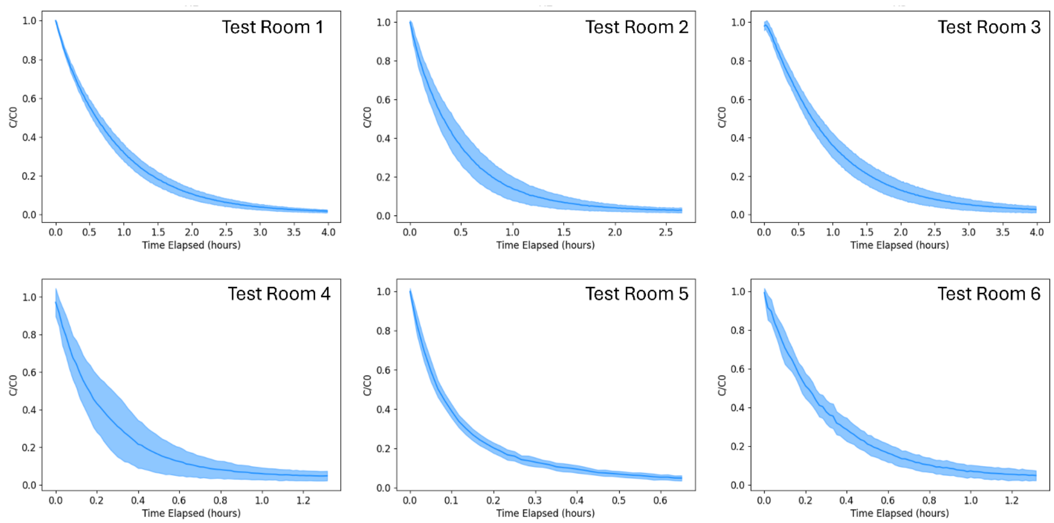

Figure 1. Background particle decay curves and air exchange rates across six test rooms. Decay curves show the normalized concentration (C/C_0) over time with ±1 σ bands (blue shading). There were at least 27 tests in each test room over the course of a week. These curves are shown to demonstrate the consistency between the findings from different teams.

Lessons learned and limitations

This Course-based Research Project was a great way to introduce first-year students to research concepts, where they build an air purifier and test its efficacy in a real-world setting. It allowed students to follow a step-by-step process of testing the purifier, collecting real-time data, and plotting the results to communicate the efficacy of the purifier. This project was carried out with over 400 students, but it can easily be adapted for a smaller classroom size. The project allowed students to accomplish multiple LOs over the course of 2 weeks and provided a good project to kick-start the semester. Although this project is rooted in indoor air pollution, various engineering disciplines (such as environmental, biomedical, civil, electrical, mechanical, multidisciplinary, and material science) benefit from data analysis and data plotting and students across the disciplines saw the benefit of the project. One limitation of the project was the designation of appropriately sized and situated testing rooms as students did not have time to go to a distant building. Each room hosted sixteen two-hour tests per week, so testing became the only activity allowed in those spaces. Students remained in the room during data collection, even though ideal research conditions require empty rooms with air purifiers and humidifiers controlled remotely. Teaching assistants managed a heavy workload to keep the large number of tests running smoothly for a large class; a smaller course would reduce this burden. In the next iteration, instructors will include a survey to evaluate whether the activity helped students learn about research.

Acknowledgements

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References

[1] National Academies of Sciences, Engineering, and Medicine, *Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities*. Washington, DC, USA: The National Academies Press, 2017.

[2] F. Assanah, K. Wagstrom, D. D. Burkey, and M. Creed, "Work in progress: Project-based service learning shapes the morals of first-year engineering students," in *Proc. 2023 ASEE Annu. Conf. Exposition*, Baltimore, MD, USA, 2023.

[3] F. Assanah, K. Wagstrom, D. D. Burkey, and M. Creed, "GIFTS: Project-based service-learning for first-year engineering students," in *Proc. 2024 ASEE Annu. Conf. Exposition*, Portland, OR, USA, 2024.

[4] B. U. Lee, "Minimum sizes of respiratory particles carrying SARS-CoV-2 and the possibility of aerosol generation," *Int. J. Environ. Res. Public Health*, vol. 17, no. 19, pp. 1–8, 2020.

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[7] M. L. Jehn *et al.*, "Effectiveness of do-it-yourself air cleaners in reducing exposure to respiratory aerosols in U.S. classrooms: A longitudinal study of public schools," *Build. Environ.*, vol. 258, 2024.

CRB Log 1 - Background and Build

Corsi-Rosenthal Box Project: Indoor and Outdoor Pollutants and Filtration System Efficiency

Group Assignment - Choose a team leader and the leader will submit the log in HCT, ALL members will get the same grade! If your name is not there, you do NOT receive a score on the Log!

Due Date: February 5, 2024

Learning Objectives

After completing this module, you should be able to:

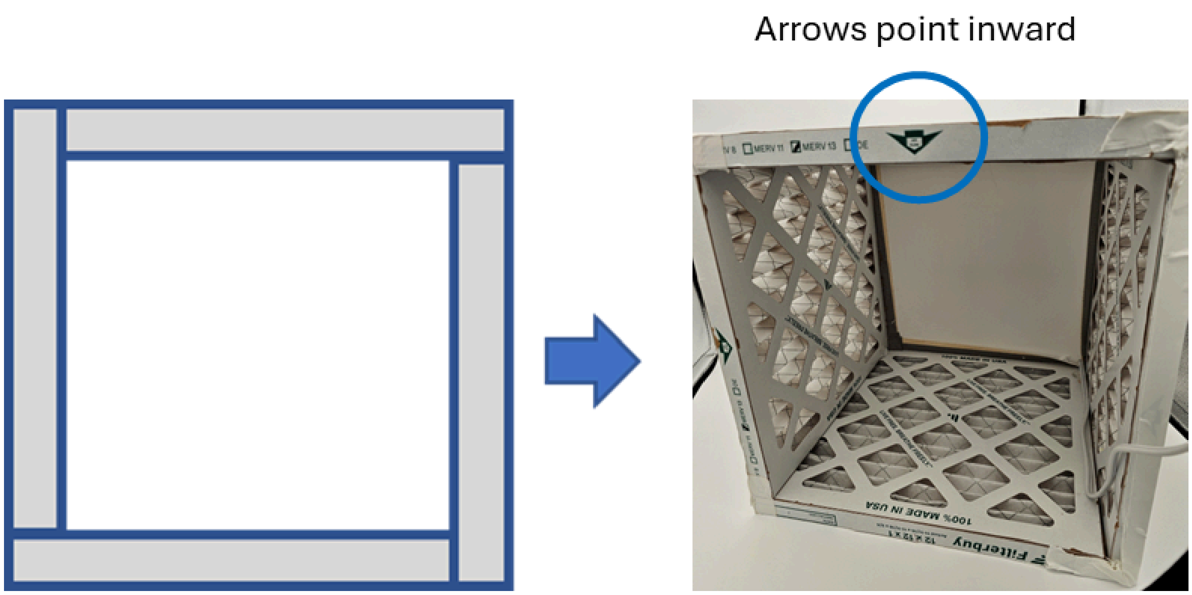
- Demonstrate LOs 3 and 4
- Understand the design of the Corsi-Rosenthal Boxair filter
- Prepare the support and four edge-attached filters
- Assess your design and suggest updates
- Complete the Build of the C-R Box
- Check Quality Control

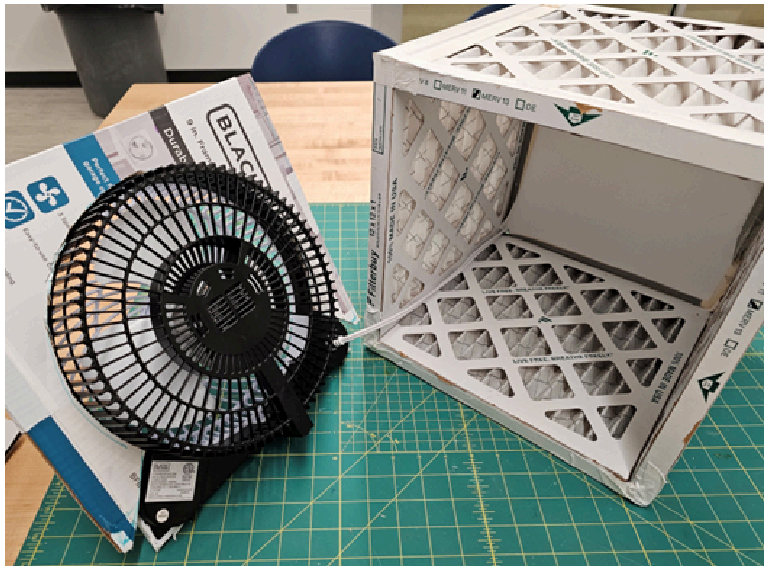
Tasks to be completed in Class as a Group:

- Gather parts list:
    - Box Fan - Black + Decker 9 inch Frameless Box Fan
    - Keep the cardboard box from the fan intact! Do not destroy it! You will need to use this!!
    - Five MERV13 12 inch filters
    - Duct tape
    - Template (available to you in the classroom, or ask the TA)

- Make basic filter structure:
    - Assemble four filters into a cube and attach filters with duct tape connecting the sides of the filter
    - ***Make sure that the "wire" side of the filters faces the inside of the cube! There are arrows on the sides of the filters to show the direction of air flow. Make sure the arrows point inwards (as shown).***

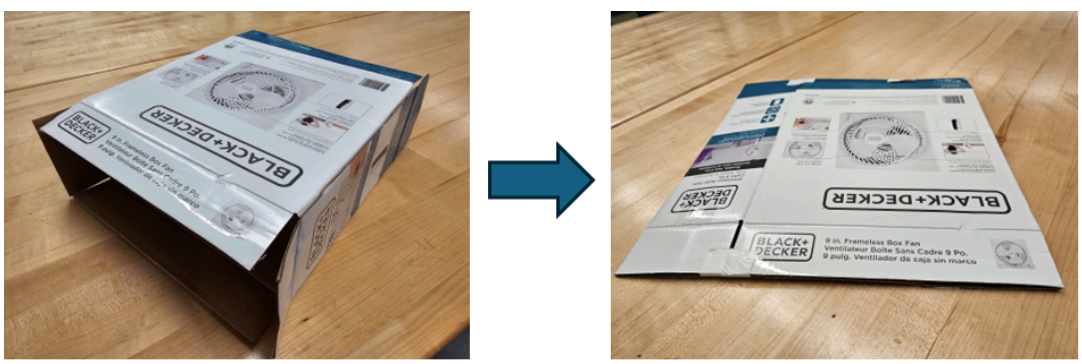
- ■ ***This is because the CRB will pull 'dirty' air through the filters and into the box, and then provide 'clean' air through the fan.***
- ○ ***The filters should be arranged on a <u>staggered 90 degree angle</u> as shown in the schematic below (sort of forms a spiral). The final shape should be a perfect square (instead of [barely] a rectangle if you don't 'spiral' the filters)!***
- ○ Connect filters with duct tape as indicated. Make sure it is air tight!
- ○ Before you connect and tape the fifth filter centered on the bottom of the 4 walls, make sure to feed the wire of the fan along the corner of the box as shown below. The fifth filter will technically be the bottom of the box.
- ○ Keep a log of the steps, take pictures of the build as you complete the various tasks. This will be IMPORTANT throughout the semester for all of your projects! - since you'll evenually need to talk about these steps in your Engineering Portfolio. **See Below.**





Feed the fan wire through the sides to the bottom of the filter box. *Remember there should be a fifth filter at the bottom, not shown here!*

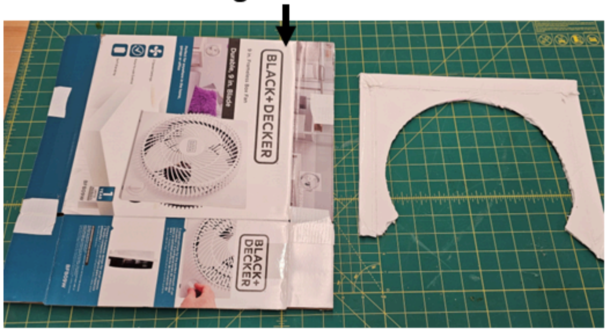
- <u>Prepare the support for the fan (measure carefully, and be careful not to damage fingers/tables/floors while cutting).</u>
    - Take the intact box of the fan and collapse it. This will give you a double-layer flat piece of cardboard as shown. One side is the folded edge of the box and the other side is the glued edge of the box. Do NOT cut anything yet!



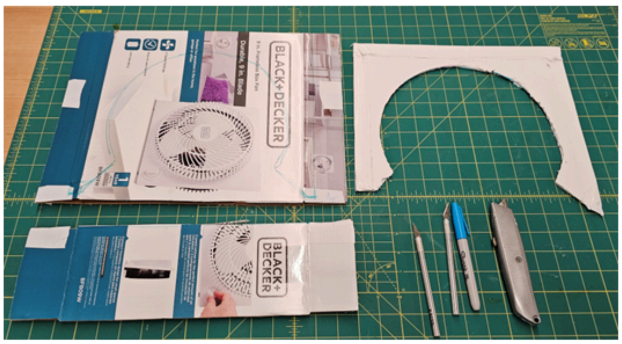
Make the box flat and tape the edges. (Just as shown!)

    - Use the template available in the room and trace the shape onto the flattened box.
    - Collect a ‘cutting sheet’ and knife or scissors.
    - Cut along the traced line. Make sure you do not cut the folded edge. This makes the support stronger!
    - Follow the images below:

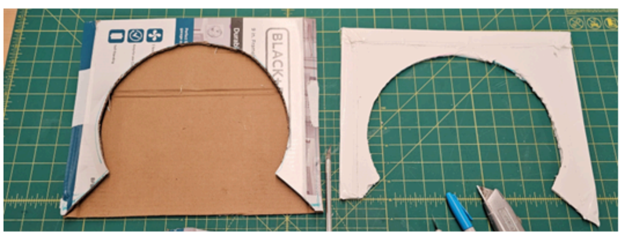
folded edge of the box



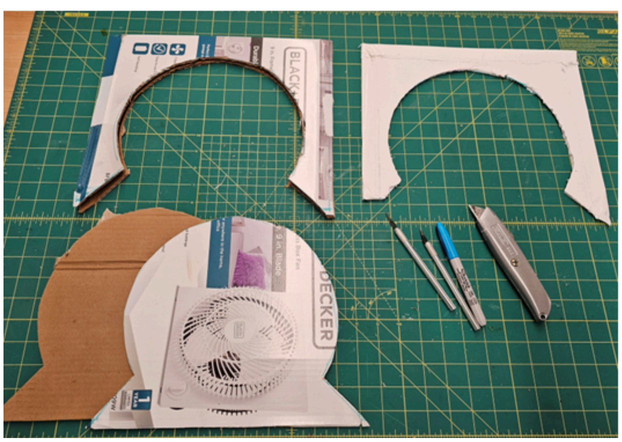
Use the template given to you and **trace** onto the flat cardboard.
Note: The folded edge of the box is at the top. Do not cut that side!



Cut the "glued" edge of the box as shown
Note: The folded edge of the box is at the top. Do not cut that side!



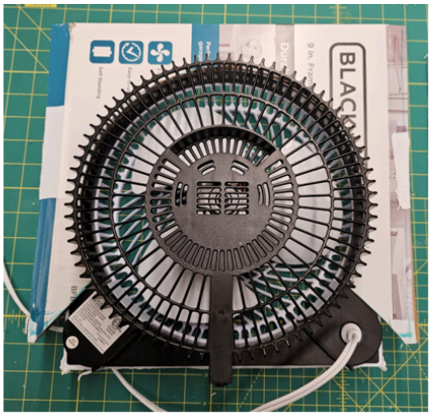
Cut along the traced line, there will be two layers to cut!



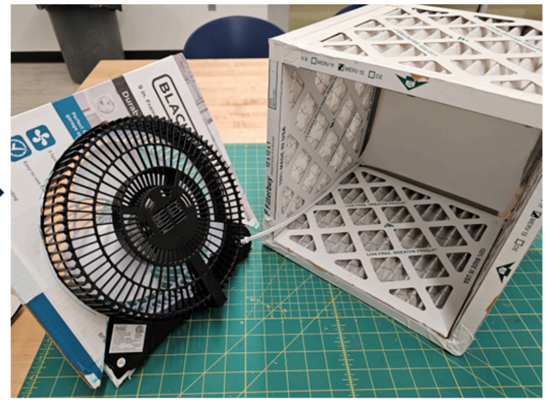
Cut the second layer of cardboard. The folded edge is on the top and should remain folded!

to cut the big cardboard (box fan packaging)

- Attach the support that you just cut to the back of the fan. It should be a snug fit as shown below:
- Place the wire cord of the fan through the filter box and feed through the side and bottom filter.
- Take pictures of the process!

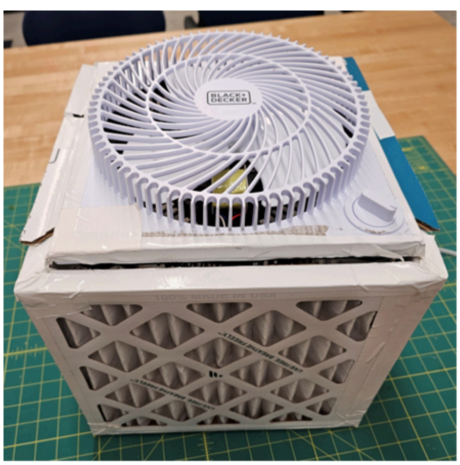


Place the support to the back of the fan and it should be a snug fit

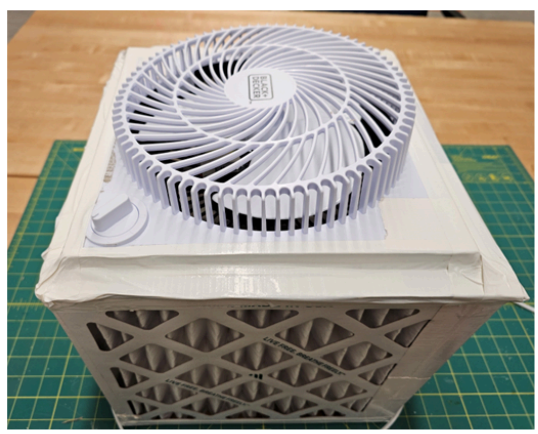


Feed the fan wire through the sides to the bottom of the filter box. *Remember there should be a fifth filter at the bottom, not shown here!*

- Attach this filter box assembly to fan with the support. **Use duct tape to ensure the openings are airtight.**
- Conduct a final visual check for leaks on the assembled unit and test to see if it works
- Keep logs for the design and tasks completed each week and remember to take pictures.
- **Plug in the unit and quickly check for any air leaks!**



Place the fan on the filter box and tape all edges firm with **DUCT TAPE**!



Completed C-R Box!

Quality Control Checklist:

- Switch teams!! Each team will have to assess another team's C-R box using the quality control checklist below. Your design instructors will assign you to the team where you will inspect their work. Any aspect that failed means that you failed inspection! You will have to rebuild the component so that your box passes inspection. Once all categories pass, the inspection team will add a sticker that indicates your C-R box has passed the inspection.

- Printouts of this inspection table will be given to you for check marks!
- Once you pass the inspection, put the UConn logo on your box (will be provided to you!). Decorate of write a respectful message to the Veterans, if you want. Please be respectful and do not write inappropriate things. Remember you are representing your institution!
- Label your box with you and your teammates names on a postit note to identify your box - you will use the same box to run air quality tests next week, so you should know which one is your box.

NOTE: Below is just to show you what is the quality Control Check list. DO NOT WRITE IN HERE!! YOU HAVE TO CHECK IN THE PRINTED SHEET!!

Checklist	Pass	Fail
Use duct tape		
Filters oriented correctly		
Fan oriented correctly		
No gaps in tape		
Cable is accessible		
Sturdiness		

Deliverable: Engineering Log *(submit in HuskyCT as a Group Assignment)*

Read the background materials and the video provided in HuskyCT to help you answer the questions below.

1. Why is it important to have a DIY, portable Air filter? Why are you building the C-R Box and where will the box be donated in 2024?
2. Create and include a 'Gantt chart,' which displays the timeline for each step of the building process. These charts are a common project management tool used to help engineering project teams identify milestones and deadlines, plan other obligations relative to the project timeline, and track performance. Feel free to copy and then modify the example provided in HuskyCT. Important elements are based on:
    a. What are the key steps for planning, building, testing, and refining the CRB?
    b. Estimate how many hours of effort each step will take.
3. Describe the building process. Include some pictures that you took of your build, as appropriate. What aspects of the build were important and why?

4. Who is chiefly responsible for each part of the process (best practices are to always have one lead per main task and deadline–this shows up in the "Main Responsibility" column of the Gantt chart)?
5. Suggest 2 possible improvements to the functionality of the basic design (what do you suggest, and why). You might consider the filter type, the fan type, the overall design, etc.
6. Can you think of a way to update the design to accommodate relatively easy replacement of the filters (since they won't last forever)?

Engineering Log Format

Your Engineering Log should be **2-3** (minimum-maximum) pages long (approximately 800 words, Times New Roman, font size 12), and it should include the following information:

- **Objective:** What was the objective of this laboratory assignment? *- short paragraph.*
- **Answers** to the 6 questions listed above in the "Deliverable: Engineering Log" section. Include the Gantt chart , and relevant pictures that you took during the planning and building process. *- short paragraph with respect to the questions above*.
- **Next steps:** What is your immediate next design step, depending on what you have done in this assignment? *- short paragraph.*

Engineering Log Rubric:

	Mastery (3)	Competent (2)	Emerging (1)	No Evidence (0)
Rubric	Student/group completes the module deliverable and incorporates all required elements. The work is professional, well documented, and generally without error.	Student/group completes the module deliverable and incorporates the required elements. The work is acceptable, but may not be well documented or explained. There are some conceptual errors in their work that should be corrected.	Student/group completes some but not all of the module deliverables. The work presented is lacking in one or more significant ways, and may have conceptual errors that need to be addressed. The explanation and documentation of the work is minimal.	The student/group does not submit any of the module deliverables.

CRB Log 2 - Testing

<u>Corsi-Rosenthal Box Project</u>: Indoor and Outdoor Pollutants and Filtration System Efficiency

Group Assignment (team leader and the leader will submit the log in HCT) - same team
Due Date: February 12, 2024

Learning Objectives

After completing this module, you should be able to:

- *Demonstrate operability of the CRB air filter*

Test Room Information

Team 1, PWEB 180 (formerly UTEB 180 - Storage room) Room volume: 36.5m^3
Team 2, E2 114G , Room volume: 45.3m^3
Team 3, E2 114F, Room volume: 52.5m^3
Team 4, PWEB 158 (formerly UTEB 158), Room volume: 43.0m^3
Team 5, PWEB 286 (formerly UTEB 286), Room volume: 28.6m^3
Team 6, PWEB 270 (formerly UTEB 270), Room volume: 44.2m^3

Tasks to be completed in Class as a Group:

NOTE: There are <u>two parts to this assignment</u>

1) Data Collection: This is the testing experiment that you will carry out with your C-R Boxes, in separate rooms

2) Data Plotting and Calculations: These are the data analysis steps you will perform after you get your data

1. Data Collection

Here is a video for your guidance but read the instructions first! Link

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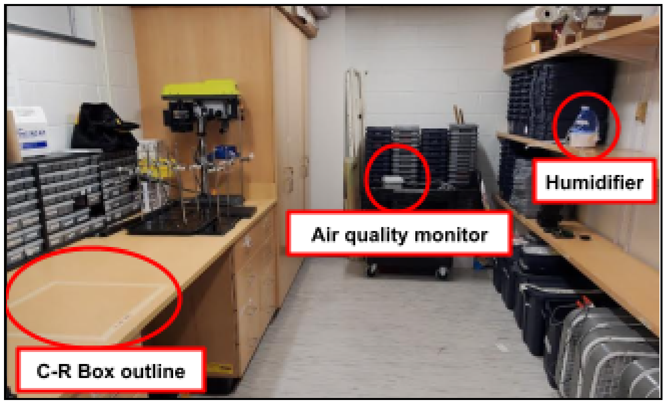
Pre-Test Preparation

- Each team will be assigned a different room equipped with a **humidifier** and an **air quality monitor (already in the room)**. Be sure to handle the C-R Box with care during transportation. Do **NOT** move the humidifier and air quality monitor!



- On the door of each test room, you should see a sign like the one below. Please check the sign on your test room door. Make sure the group number and location listed match your assigned room. Then, record the room's volume, which is also provided on the sign. Room volume is also provided in the earlier section of this document.

<u>ENGR 1166 CRB Test Room</u>
Group 1
Location: PWEB 180

Room volume: 10.4m^3
Room dimensions: 3.0 m x 1.5 m x 2.3 m

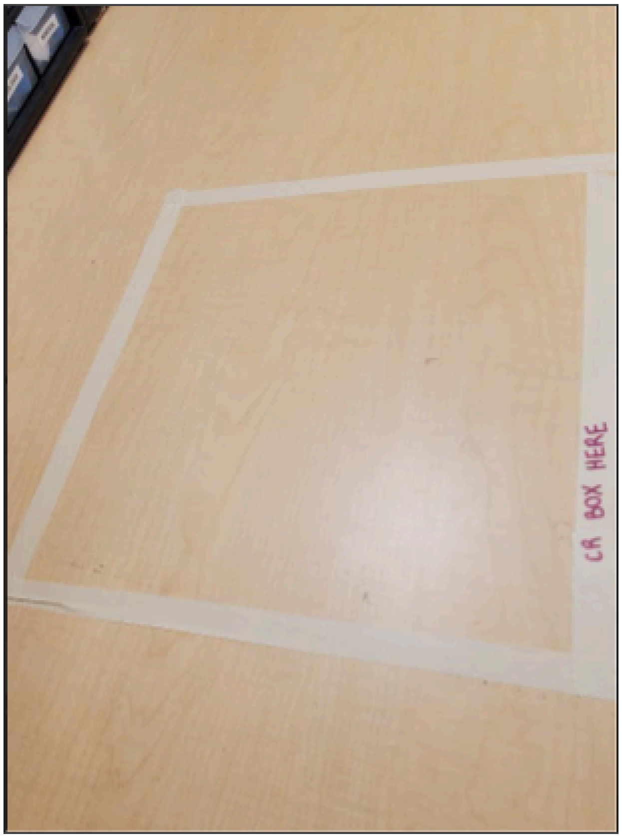
If the door is closed, please knock before entering.
Testing may be in progress!

- Begin by inspecting the humidifier to ensure it is filled with the test solution (as seen in the image on the left below). If the humidifier is not filled (as seen in the image on the right below), inform the teaching assistant (TA) before proceeding.

Humidifier filled

Humidifier empty

- Locate the marked area in the room, indicated by tape, where the C-R Box should be placed. Place the C-R Box upright in the marked area, (fan facing upward) ensuring that it's stable and properly aligned. Plug the C-R box in and test the C-R box to see if it turns on. If it does not turn on, inform the TA immediately. Otherwise, turn it off.



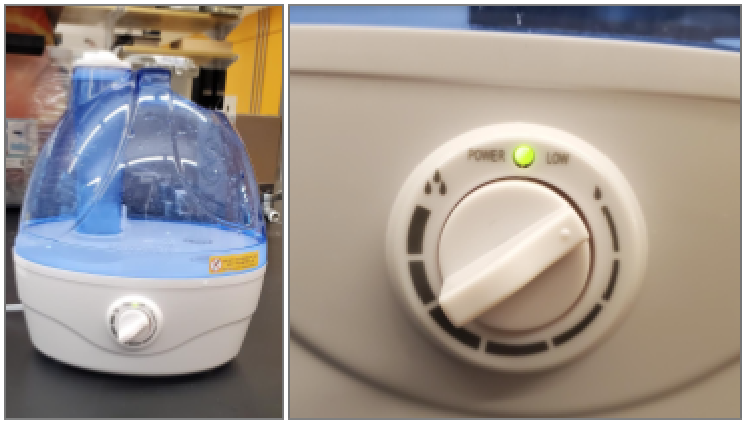
C-R box outline

C-R box placement

- **Precautions.** Do not obstruct the four of the five sides or the outlet of the C-R Box during the test. Maintain a safe distance from the C-R box, humidifier, and the air quality monitor. Do not move or adjust the C-R Box, humidifier, and air quality monitor during the test unless instructed otherwise. In case of any equipment malfunction, report immediately to the TA and **do not attempt to fix the equipment yourself.**

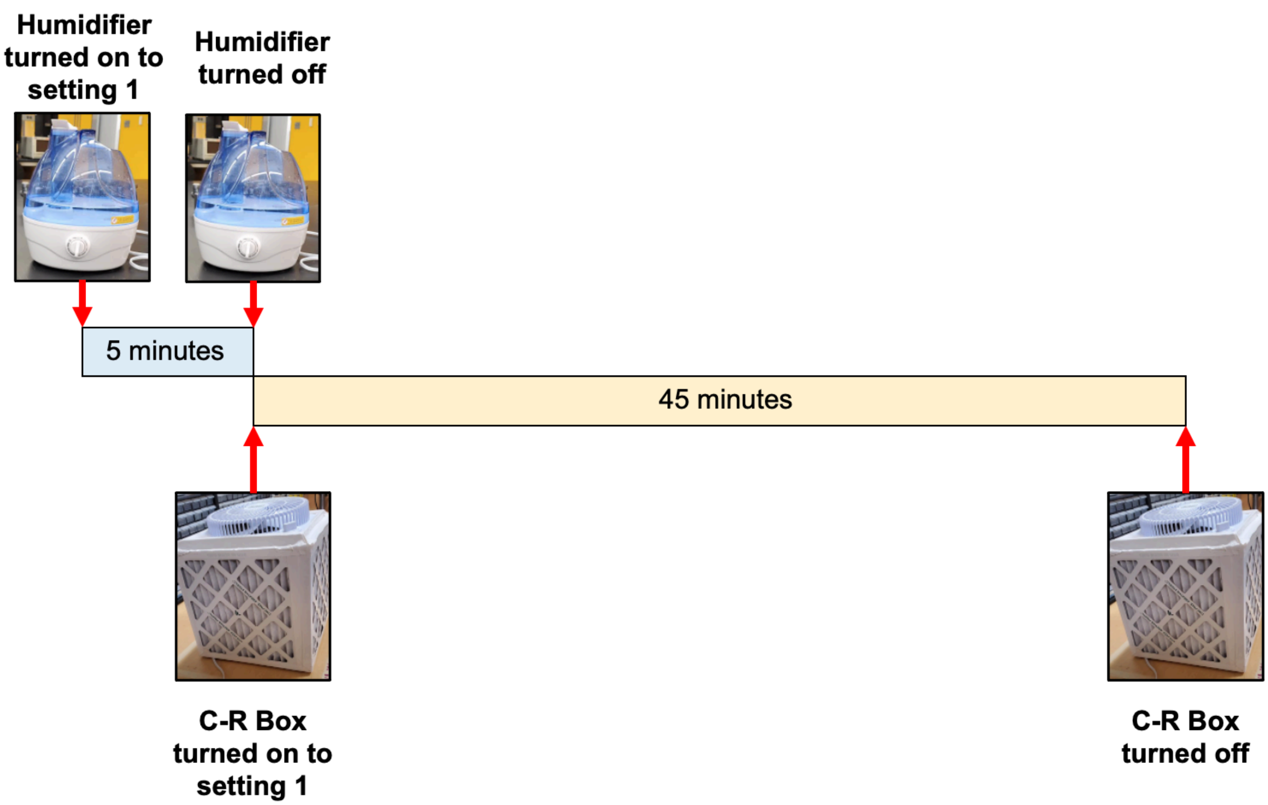
PM Reduction Test.

- **For the duration of the test, only 3 members of the team should be in the room at once. Please ensure that any windows and doors are closed before you begin testing. Read <u>all instructions in this section</u> at least once before you begin.**
- Turn the humidifier on to setting 1. A green light indicates that the humidifier is on. Record the time you turned on the humidifier. **If there is a red light, turn off the humidifier and inform the TA to refill. Record this time! You need to provide this in your log!**



- Start the timer (on your phone or any other device) and let the humidifier run for 5 minutes to introduce aerosols into the room's atmosphere. **If there is a red light at any point during this 5 minute window, record the time you notice the red light, turn off the humidifier and immediately inform the TA.**

- Below is a diagram showing a summary of the experimental schedule.



- After 5 minutes, turn off the humidifier and immediately turn on the C-R Box to **level 1** setting. Record the time when you turned the C-R box on.

- Set the timer for 45 minutes and allow the box to operate uninterrupted. Once the 45 minutes have elapsed, turn off the C-R Box. Record the time you turned off the C-R box. If there is an issue with the C-R Box during this 45 minute window, inform the TA immediately. **Record this time! You need to provide this in your log!**
- After the test, remove the C-R Box from the room and check the level in the humidifier. Inform the TA when you are done and if the humidifier needs to be refilled. **Return your C-R Box to PWEB 180. Leave everything else (the humidifier and air quality monitor) as you found it in the room**.

YOU ARE NOW DONE WITH THE TESTING EXPERIMENT!

2. Data Plotting and Calculations

Here is a video for your guidance but read the instructions first! Link

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Data Collection and Data Retrieval.

- All data from the air quality monitor will be automatically recorded and stored on an SD card.
- **The TA will email the this dataset to the team lead at the end of the day.**
- The data file will contain two columns:
    - Time elapsed (in minutes)
    - $PM_{2.5}$ concentration (in micrograms per cubic meter: μg/m^3).

Preparing your Data for Analysis.

- Additional columns are needed to prepare and preprocess the collected air quality data for analysis. Refer to the excel module activity for an example of the preprocessing steps required. For all added columns, include appropriate column titles in row 1.
- **Time Elapsed Column (Hours).** Add a column to track the time elapsed during the testing in hours. This can be calculated by dividing the time elapsed in minutes by 60. Use the formula =A2/60 in cell C2, and drag it down to apply it to all cells in the column.
- **Normalized $PM_{2.5}$ Column.** Create a column for normalized $PM_{2.5}$ values. The normalization is done by dividing the $PM_{2.5}$ value by the maximum value in the $PM_{2.5}$ column to scale the data between 0 and 1. Use the formula =B2/MAX($B$2:B[last_row_number]) in cell D2 where B2 is the $PM_{2.5}$ value for that row, and [last_row_number] is the row number of the last data entry. The $ signs in $B$2:B[last_row_number] make the cell reference absolute, which means when you drag the formula down, it will always divide by the maximum value of the original $PM_{2.5}$ column. Drag it down to apply it to all cells in the column.
- **Natural Log.** Create a column for the natural log of the normalized $PM_{2.5}$ values. Use the formula =LN(D2) in cell E2, and drag it down to apply it to all cells in the column. See Appendix A for a sample spreadsheet with calculated values.

Performing the Data Analysis.

- The data collected during the C-R Box testing can be used to estimate the Air Change per Hour (ACH) and Clean Air Delivery Rate (CADR).
  - ACH refers to the number of times an air purifier can effectively filter and clean the entire volume of air within a specific space in one hour. A higher ACH value means that the indoor air is being refreshed more frequently, which can help reduce the concentration of indoor pollutants and improve air quality.
  - CADR is a standardized measurement of an air purifier's ability to remove specific indoor pollutants from the air
- <u>This exercise has been done in the EXCEL module and you should be familiar with carrying out this analysis. If you are in doubt refer to the EXCEL and Data Plotting Module on HuskyCT.</u>
    - **Scatter Plot with Linear Regression to Calculate ACH.** Create a plot similar to the plot created in the Excel Activity using appropriate axis labels. Column E (ln of particle concentration) becomes the y data series and Column C (time) becomes the x data series. With the scatter plot selected, go to the 'Chart Tools' or 'Chart Design' tab. Click on 'Add Chart Element', select 'Trendline', and then choose 'Linear'. To display the equation on the chart, select the trendline, and then go to 'Trendline Options'. Check the box for 'Display Equation on chart'.
    - **Find the ACH.** Take the slope from the equation displayed on the chart and multiply it by -1. This becomes your <u>ACH value</u> and will have units of inverse hour (h^{-1}).

- **Calculate CADR.** Once you have the ACH, calculate the CADR using the room volume in cubic meters (m^3) provided. Use the formula CADR = ACH × V. The CADR will have units of cubic meters per hour ($m^3\ h^{-1}$).

Discussion

1. How do you predict the data would change using multiple CRBs?
2. Do you think the placement of the CRB would impact its efficacy?
3. How do different room sizes and shapes affect the performance of the C-R Box?
4. Would temperature and humidity affect the efficacy of the C-R Box?
5. How do different operating levels of the C-R Box affect the ACH and CADR?
6. Would a longer testing time significantly change your calculated ACH and CADR?
7. Would a longer operation time significantly change the particle concentration in the room?

Deliverable: Engineering Log *(submit in HuskyCT as a Group Assignment)*

1. Now that you've completed building and testing, recommend 2 improvements for a "Version 2.0" filter system. Perhaps make it more durable, safer (especially childproofing), more efficient (a different shape and/or multi-stage filtering?), easier to replace the filters, cheaper, more recyclable, etc. Be creative…
2. Include the **Scatter Plot with Linear Regression** that you made using Excel for this assignment. Make sure you have the proper axis, labels and legends. If you need more information refer to the Excel Module during Week 2 Lab.
3. Include the tables summarizing the results of ALL of your testing as outlined in the **activities** above.

ACH (h^{-1})	
CADR (m^3/hr)	
Time you turned humidifier ON	
Time you turned humidifier OFF	
Time you turned CRB ON	
Time you turned CRB OFF	

4. Include the answers to the discussion questions above (1-7)
5. Prepare an updated gantt chart with final tasks, primary actual responsibilities, and actual (realized) timeline. Explain any changes to the plan and timeline. Include whether those changes were caused by one-off challenges, or are modifications you would need to incorporate for future implementations of this (or any similar) design.

Engineering Log Format

Your Engineering Log should be **2-3** (minimum - maximum) pages long, (approximately 800 words, Times New Roman, font size 12) and it should include the following information:

- **Objective:** What was the objective of this laboratory assignment? *- short paragraph.*
- **Answers** to the questions listed in the Deliverable: Engineering Log section (5 questions). Include the Gantt chart in this section and any picture that you took throughout this part of the build and assessment process. *- short paragraph with respect to the questions above*.

Engineering Log Rubric:

	Mastery (3)	Competent (2)	Emerging (1)	No Evidence (0)
Rubric	Student/group completes the module deliverable and incorporates all required elements. The work is professional, well documented, and generally without error.	Student/group completes the module deliverable and incorporates the required elements. The work is acceptable, but may not be well documented or explained. There are some conceptual errors in their work that should be corrected.	Student/group completes some but not all of the module deliverables. The work presented is lacking in one or more significant ways, and may have conceptual errors that need to be addressed. The explanation and documentation of the work is minimal.	The student/group does not submit any of the module deliverables.

Appendix A: Sample spreadsheet with calculated values.

time_elapsed_minutes	pm25_ugm-3	time_elapsed_hours	normalized_pm25	ln_normalized_pm25
0	267.991	0	1	0
1	234.699	0.016666667	0.875771948	-0.132649556
2	201.482	0.033333333	0.751823755	-0.28525335
3	176.088	0.05	0.657066842	-0.419969528
4	157.395	0.066666667	0.587314499	-0.532194829
5	141.751	0.083333333	0.528939405	-0.636881401
6	123.716	0.1	0.461642369	-0.772964782
7	114.026	0.116666667	0.425484438	-0.854526905
8	101.779	0.133333333	0.379785142	-0.968149602
9	92.116	0.15	0.343727961	-1.067904745
10	82.985	0.166666667	0.309655921	-1.172293529
11	76.26	0.183333333	0.284561795	-1.256804843
12	69.378	0.2	0.258881828	-1.351383583
13	62.208	0.216666667	0.232127198	-1.460469789
14	55.637	0.233333333	0.207607718	-1.57210495
15	51.243	0.25	0.191211645	-1.654374375
16	46.343	0.266666667	0.172927449	-1.754883142
17	44.216	0.283333333	0.164990615	-1.801866683
18	41.038	0.3	0.153132008	-1.876454931
19	36.935	0.316666667	0.137821793	-1.981793787
20	32.344	0.333333333	0.12069062	-2.114524866
21	30.458	0.35	0.11365307	-2.174604712
22	28.802	0.366666667	0.107473758	-2.230508569
23	27.28	0.383333333	0.101794463	-2.284799565
24	24.554	0.4	0.09162248	-2.390078624
25	23.435	0.416666667	0.087446967	-2.436722766
26	21.831	0.433333333	0.081461691	-2.50762242
27	20.191	0.45	0.075342082	-2.585716437
28	19.663	0.466666667	0.073371867	-2.612214701
29	16.673	0.483333333	0.062214776	-2.777162753
30	16.394	0.5	0.061173696	-2.794037984
31	15.816	0.516666667	0.059016907	-2.829931312
32	14.127	0.533333333	0.052714457	-2.942865538
33	13.809	0.55	0.05152785	-2.965632844
34	12.773	0.566666667	0.047662048	-3.04361983
35	12.678	0.583333333	0.047307559	-3.05108519
36	11.35	0.6	0.042352169	-3.161735654
37	10.76	0.616666667	0.040150602	-3.215117843
38	9.863	0.633333333	0.036803475	-3.302163016
39	10.016	0.65	0.037374389	-3.286769583
40	9.255	0.666666667	0.034534742	-3.365789452
41	8.242	0.683333333	0.030754764	-3.481710365
42	8.461	0.7	0.031571956	-3.455486028
43	8.038	0.716666667	0.029993545	-3.506773102
44	6.964	0.733333333	0.025985947	-3.650199376
45	7.021	0.75	0.026198641	-3.64204774
46	6.569	0.766666667	0.024512017	-3.708591784
47	6.324	0.783333333	0.023597807	-3.746601479
48	5.786	0.8	0.021590277	-3.835512191
49	5.944	0.816666667	0.022179849	-3.80857109