Climate, Aerosols, and Human Health

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Introduction

Aerosols are small solid or liquid particles suspended in the air. From a climate standpoint aerosols are important because they can alter the planetary radiation balance. Unlike greenhouse gases that have long atmospheric residence times, aerosols are generally removed in days. Thus, their distribution tends to be heterogeneous, with larger aerosol concentrations near their sources. This means that the climate forcing due to aerosols is highly regional.

In order to model the climate effect of aerosols it is necessary to know the spatial distribution of aerosols. At this time, the spatial distribution of aerosols is poorly known and the climate forcing provided by aerosols is one of the largest uncertainties in current climate simulations (Hansen and Lacis,1990). While the sign of the total aerosol forcing is uncertain, it is clear that the radiative forcing associated with sulfate and nitrate aerosols is negative. Thus, these aerosols produce a cooling that can potentially offset some of the warming due to increasing concentrations of greenhouse gases.

Aerosols have both natural and anthropogenic sources. Examples of natural sources of aerosols are wind-blown desert dust, and sea salt. Anthropogenic aerosols tend to be associated with combustion by-products. Examples of anthropogenic aerosols are sulfates and nitrates. These can be either emitted directly as aerosols (primary aerosols) or produced from gas phase reactions (secondary aerosols) of SO_2 and NOx. Thus, in addition to being interested in the spatial distribution of aerosols, we are also interested in the spatial distribution of aerosol precursors (SO_2 and NOx).

In addition to their role in climate, aerosols are also of interest because they decrease visibility, contribute to acid rain, and can affect human health. Numerous international studies have looked at the relationship between aerosols and increased mortality. According to a recent international Commonwealth Science Council conference, air pollution kills eight thousand people every day worldwide.

The health impacts of aerosols consist of both short-term acute symptoms, like asthma and bronchitis, and long-term chronic irritation and inflammation of the respiratory track, which can potentially lead to cancer. Epidemiological studies of the impact of aerosols on human health have tended to focus on particular events. For example, during the haze episode in late September to early October 1997 in Thailand, a substantial increase of about 7% in respiratory morbidity was observed in 2 city hospitals in Hat Yai City (K. Phonboon in Health and Environmental Impacts from the 1997 Asian Haze in Southern Thailand). Moreover, during this relatively short time period there was a significant increase in hospitalizations for upper respiratory tract infections (15%) and bronchitis (49%). Additionally, epidemiological studies have found a correlation between daily mortality, daily hospitalization data and particle concentrations in outdoor air. These studies are central to the decision of the EPA to propose new tighter particle standards.

Of particular interest is asthma. Asthma is a chronic inflammatory disorder of the lungs characterized by episodic and reversible symptoms of airflow obstruction (NIH). During 1993-1994, an estimated 13.7 million persons in the United States reported having asthma, and from 1980 to 1994 the prevalence of self-reported asthma in the United States increased 75% (CDC). In 1998, asthma affected an estimated 17,299,000 persons in the United States. The state with the largest estimated number of persons with asthma was California (2,268,300), followed by New York (1,236,200) and Texas (1,175,100). State-specific prevalence rates ranged from 5.8% to 7.2%. Differences in asthma prevalence rates between states were not significant. By region, 1-year period prevalence estimates ranged from 6.4% to 6.8% in the Northeast, 5.8% to 6.1% in the South, 6.6% to 6.7% in the Midwest, and 6.0% to 7.2% in the West. The narrow range of prevalence rates within each of these regions indicates that state-specific differences in demographic composition minimally influenced estimated asthma prevalence. However, surveys of self-reported asthma prevalence in Bogalusa, Louisiana (Farber *et al.*, 1997), Chicago, Illinois (Persky *et al.*, 1998), and Bronx, New York (Crain *et al.*, 1994) all indicate higher asthma rates.

Thus, while some asthma survey data exists on regional to national scales to determine prevalence, most epidemiological studies have relied on the use of mortality and hospitalization data to examine the relationship between asthma and pollution. As noted by Claudio *et al.* (1999), these studies may contain an inherent socio-economic bias.

For this project, we sought to address knowledge gaps regarding the health effects of particles by collecting and analyzing asthma and aerosol data. In contrast to previous studies, we also examine the relationship between asthma and pollution on a variety of space and time scales. In the next section we present the methods used in this investigation. We then present our results and discuss the implications of our results.

Methodology

We used a survey to investigate the nature and distribution of asthma. This survey was first administered to randomly selected students in several New York City high schools in the spring of 2000. A revised survey was administered in winter 2001 followed by a spring 2001 survey. A total of 3,847 students were surveyed.

In order to analyze the surveys, the survey data was entered into Excel spreadsheets. In addition to asking common questions about asthma, race, age, gender, where you live, etc., each survey had a specific focus. For example, the Spring 2000 and Winter 2001 surveys attempted to ask questions that would allow us to investigate the relationship between asthma and proximity to traffic while the Winter 2001 and Spring 2001 surveys included questions focused on the relationship between asthma and allergies.

To provide the most representative look at asthma in the New York Metropolitan area, the results from all three surveys were combined into a single comprehensive data set. In addition, subsets of the data were analyzed to examine specific questions. For example, to address the representativeness of the survey data, same-school survey results were compared. We also evaluated the survey's socio-economic indicators (type of school lunch and type of medical care) against actual socioeconomic data available from the Census.

The survey analysis consists of determining the percentage of survey respondents that answered yes to a particular question. For example, we determine the prevalence of asthma by counting the number of "yes" responses to the "Do you have asthma?" question and dividing that number by the total number of responses (yes and no).

In addition to analyzing the survey data, we also constructed a data set on the global distribution of asthma from available journal articles and websites. Similarly, we constructed global pollution data sets using emissions data, ambient pollution measurements, and model results for comparison with the global distribution of asthma.

To examine the distribution of aerosols and their precursors we used a combination of sunphotometer and EPA ambient air measurements (DEC site). A sunphotometer is an instrument that measures the amount of sunlight (in voltages) that is transmitted through the atmosphere. By making measurements throughout the day, we obtain data for a variety of different air masses. An air mass is a term that refers to the amount of atmosphere that the sunlight must pass through to reach the sunphotometer. An air mass equal to one corresponds to the sun directly over head. The largest air masses occur near dawn and dusk when the sun is low on the horizon and the slant path distance that the sunlight must travel through the atmosphere is greatest. There is a simple relationship between the variation of sunlight (voltage) and air mass called Beer's Law. We use Beer's Law to generate the Langley Regression. Simply stated Beer's Law is:

$$\mathbf{V = V_0\, e^{-m\tau}}$$

or

$$\mathbf{\ln V = \ln V_0 - m\,\tau}$$

where V is the sunphotometer reading measured in Volts, V_0 is the extraterrestrial constant measured in Volts (inferred from the y-intercept, when the line is extrapolated to zero air mass), e is 2.71828 (ln e = 1), m is the airmass, and tau (τ) is the total optical thickness.

For the handheld sunphotometer spectral band, 500-560 nm, the total optical thickness is the combination of the aerosol optical thickness and the opacity contributed by gaseous absorptions. Gaseous absorbers within the handheld spectral band are ozone and NO_2. Since, we have only one measurement we can only determine a single total optical thickness and can not detect hourly variations.

In our investigation of aerosols we focused on a couple of questions. We used the EPA data to examine the spatial variation of aerosols, measured as the density of particles smaller than 2.5 μm in size ($\mu g/m^3$), as well as the relationship between aerosol precursors and other measures of tropospheric pollution, like ozone and carbon monoxide. As a separate component, we collected and analyzed additional handheld sunphotometer data to determine the reliability of the instrument through handheld intercomparisons and the comparison of the handheld-derived optical depths with those measured by the CIMEL automated sun-tracking sunphotometer located on the roof of GISS.

Results

Since the global patterns of asthma and pollution may provide insights into the connection between pollution and asthma, we examined the global distribution of asthma. While in some sense international asthma data are plentiful, inconsistencies between reports and temporal differences in the availability of data in the presence of an increasing asthma trend complicate this analysis. Our best determination of the global distribution of asthma is shown in Figure 1. This figure shows that the distribution of asthma is highly heterogeneous with asthma being most prevalent in New Zealand, Australia and the United Kingdom.

Figure 1 Global distribution of asthma in 1999

The global picture of asthma provides some interesting insights since the populations in contrasting regions share similar genetic heritages. For example, contrasting low asthma rates in China to the high asthma rates in Hong Kong can argue against genetic factors in favor of environmental factors.

Analysis of the survey data

The survey data reveal that the prevalence of asthma in the New York metropolitan area is 14%. This value is significantly higher than that reported on the state level and supports the higher value of self-reported asthma in the Bronx (Crain *et al.*, 1994). We further examined the distribution of asthma by sorting the data by borough. Figure 2 shows our results for Manhattan, the Bronx, Queens, and Brooklyn. Staten Island and Long Island have been omitted due to the limited number of responses in from people in these regions. As can be seen, we find that Manhattan has the highest prevalence of asthma. This is in contrast with the results of hospitalization and mortality data that, if used to infer prevalence, indicate that asthma rates are highest in the Bronx.

Figure 2. Distribution of asthma by borough

We analyzed the prevalence of asthma by race. Figure 3 shows the results of this analysis. Consistent with previous studies we find that the prevalence of asthma is higher among Hispanics and blacks than whites and Asians. However, in this determination we have not controlled for possible socioeconomic factors.

Figure 3. Distribution of asthma prevalence by race

In order to determine how meaningful the survey results are we performed a number of investigations of the survey data. For example, one concern with the survey is that we are asking people to tell us in which season they have the highest number of asthma attacks. The response to this question may depend on when the survey is administered. To address this, we compared the response to this question across all surveys and found that in all cases the most frequent response is winter. A similar result was found when comparing the Winter 2001 and Spring 2001 surveys for Frederick Douglass Academy (FDA), the only school surveyed twice. Figure 4 shows the FDA results.

Figure 4. FDA winter.

In addition to comparing results across surveys, we investigated whether or not our intended socio-economic proxies are actually related to socio-ecomic data. In this analysis, it is only possible to use the results from the Winter 2001 and Spring 2001 surveys since the earliest survey did not contain these questions. To determine whether the type of lunch a student has is related to income, we added income information from the Census data based on the zipcode of the respondent. Figure 5 shows the results to this comparison.

Figure 5. Comparison of type of lunch and income

As can be seen, the fraction of students receiving a free lunch decreases with income (white bars). Thus in a statistical sense, type of lunch and in particular free lunch can indicate socioeconomic status.

Figure 6. Comparison between type of medical care and income

To investigate whether or not previous asthma studies that have relied on the anlaysis of hospitalization data contain a socioeconomic bias, we compared the survey respondent's type of medical treatment with his/her zipcode income, determined from Census data. As can be seen from Figure 6, the percent of students seeking emergency room treatment for asthma decreases with income, while the percent of students seeking treatment from their family doctor increases with income. This result strongly suggests that hospitalization data contain a socioeconomic bias because it does not sample this higher income group.

Interestingly, we found no relationship between asthma prevalence and socioeconomic indicators (type of lunch or type of medical care). This suggests that the racial differences previously shown in Figure 3 are not the result of socio-economic differences but may be due to other factors such as racial differences in the proximity to pollution.

To further examine the representativeness of the survey data, we compared the results of the two FDA surveys. We found that while the prevalence of asthma determined from the Winter surveys is consistent with that determined from the analysis from all of the survey data (15% vs. 14%), the Spring FDA survey finds a higher prevalence (21%). This suggests that either the survey does not accurately capture the prevalence of asthma or that there are real differences in the population of FDA students surveyed in the Winter and Spring. Figure 7 shows the variation in asthma prevalence with gender. This figure shows that for both surveys, females have a higher prevalence of asthma than males. This is counter to the result we obtain from the analysis of all of the surveys but is consistent with the published relationship between asthma prevalence, gender and age.

Figure 7. Gender Differences in Asthma Prevalence

Figure 8 shows the gender breakdown of the FDA survey respondents for the Winter and Spring surveys. From this plot we can see that more females were surveyed in spring than in winter which, when combined with the higher asthma prevalence among females than males, results in the higher overall prevalence of asthma in the Spring survey results.

Figure 8. Gender Differences in Survey Respondents

We used the FDA data to investigate whether there is a relationship between asthma and allergy. We found that the majority of people with asthma also have allergies but that the majority of people with allergies do not necessarily have asthma. This association between asthma and allergies provides a link to the physical mechanism through which pollution can impact both the severity of an allergic response and asthma. Physiological studies have shown that increasing NO_2 concentrations lower the threshold of allergen exposure required to trigger an allergic reaction and may similarly lower the threshold required to trigger an asthma attack.

In past years, the aerosol team found differences in asthma burden (defined as the number of asthma attacks) that were related to how close the respondent lived to traffic. The relationship was strongest in the Bronx. To further examine the spatial distribution of asthma, we examined the survey results at the zipcode level. We found that some previously identified "hot" zipcodes (cf., Claudio et al. 1999), do have high numbers of people that responded "yes" to the "Do you have asthma?" question, however, when converted to percent, these zipcodes do not have the highest asthma prevalence. Instead, it appears as though there is a relationship between asthma prevalence and traffic. The zipcodes with the highest prevalence of asthma in Manhattan corrrespond to the zipcode locations of the Mid-town Tunnel on the east-side and the Lincoln Tunnel on the west-side. These zipcodes also contain truck-routes.

We examined the relationship between asthma and our socioeconomic proxies and found no relationship. Thus, there does not appear to be a relationship between asthma and income. Additionally, there does not appear to be a relationship between asthma burden and income. However, there is a relationship, shown in Figure 9, between asthma burden and parent's education. This result suggests that the parent's educational level can indicate how well the child's asthma is managed. The dark bar in the lower portion of the figure corresponds to the lowest levels of parental education. Here we see that the number of students with parents that have only some high school increases as the number of asthma attacks increases (increases from left to right). Conversely, we see that the number of students with parents that have college educations increases as the number of ashtma attacks decreases (from right to left).

Figure 9. Relationship between parent's eductaion and asthma burden.

Investigation of aerosols

In the investigation of aerosols we considered data from the handheld sunphotometers and the particulate data from the New York Department of Environmental Conservation (DEC). Additionally, we considered the distribution of aerosol precursors (SO_2 and NOx) as well as other measures of pollution (e.g., CO and ozone). Analysis of MFRSR data from several Northeastern sites reveals that the mean aerosol particle size is larger in winter than in summer (0.49 μm standard deviation 0.03 versus 0.40 μm standard deviation 0.048, respectively) however, aerosol size is more variable in summer most likely due to the influence of relative humidity on particle size during periods of enhanced relative humidity during summer. More surprisingly, this analysis reveals that aerosol sizes are fairly uniform during summer and more variable among these Northeasthern sites during winter (Alexandrov *et al.*, 2001). Aerosol optical thickness also changes with season with higher optical depths found in the summer than winter (0.23 standard deviation 0.13 versus 0.062 standard deviation 0.023, respectively). These results are consistent with a study by Schichtel (available at http://capita.wustl.edu/CAPITA/CapitaReports/PMFineAn) that shows that PM2.5 monitoring sites in urban centers are dominated by local sources during the cold season and regional sources in the warm season. Thus, while the bulk of our summertime aerosol are regional, there is probably a local enhancement since the aerosol optical depth in New York City is higher than the aerosol optical depth at the other Northeastern sites.

To investigate this, we began with an investigation of aerosol precursors. Figure 10 shows the diurnal variation of NOx concentrations. As can be seen, there is an association between the concentration of NOx and rush hour traffic.

Figure 10. Diurnal variation of NOx

Spatial differences exist throughout the New York metropolitan area. Table 1 shows the correlation between SO_2, NO_2, NOx, and CO. In this comparison CO is used as an indicator of combustion sources. Thus, from this table we can see that the correlation between CO and SO_2 is low for all three sites indicating that the SO_2 does not share a common source. However, the NOx, NO, and NO_2 abundances are all correlated with CO suggesting a common combustion source. From this we conclude that CO could be used as a proxy for the spatial variability of the nitrogen oxides. Spatial differences in the degree of correlation are most likely related to spatial differences in the strength of the combustion source.

Table 1.

Photochemistry also alters the concentration of the pollutants in the New York metropolitan area. Figure 11 shows the relationship between ozone and NOx. As can be seen the curves are anti-correlated as expected if NOx is photolyzed to produce ozone.

Figure 11. Relationship between ozone and NOx.

While ozone is photochemically produced in all seasons, the temperature dependence of the photolysis rates combined with the decrease in available sunlight in winter produces a seasonal cycle in tropospheric ozone. Thus, due to this difference in the strength of the NOx sink, a constant NOx source would result in higher NOx concentrations in the winter due to the smaller photochemical loss. This can be seen in the seasonal variation of NOx concentrations.

In addition to finding spatial variations in the concentration of aerosol precursors, there are also spatial variations in the concentration of particulates. Figure 12 shows that variation of PM2.5 in the New York Metropolitan region.

Figure 12. Spatial variation of PM2.5

One of our primary tasks was to assess the accuracy of the heand-held sunphotometer measurements through comparison with CIMEL measurements made on the roof of GISS. At a glance, it appears that on some occasions the hand-held optical depths are in excellent aggreement with the CIMEL results, but on other occasions the results differ by a factor of two. This type of accuracy would greatly limit the utility of the handheld measurements. However, closer examination of the data reveals a pattern. The data suggest (1) that in order to get a good Langley Regresssion you need to make measurements over a wide range of airmasses. Thus, since the airmass did not change much during summer institute hours (10 AM to 4 PM), the bulk of our data are limited to airmasses less than 2. Comparison of the CIMEL and handheld results as a function of airmass, suggests a convergence between the optical depths when the hand-held retrieval is based on a broader range of airmass values. Nonetheless, these results suggest that there may be a bias between the hand-held and CIMEL-determined optical depths due to calibration difference. (Note that the CIMEL data used here are preliminary and have not been cloud-screened or had the final calibration applied).

Figure 13. Hand-held CIMEL Comparison

Looking more carefully at the CIMEL/hand-held comparison it is also possible that the airmass effect noted above is due to changes in optical depth during the day. Better agreement may be found when the data periods are better matched. However, by sampling the CIMEL data to match the times of the hand-held measurements and comparing the matched data sets, we found no better agreement.

Discussion

The dramatic increase in asthma prevalence combined with the decrease in airborne pollutants has made many question the role of pollution in the asthma increase. Our results, in particular the emerging spatial pattern of asthma, strongly suggest a link between asthma and pollution. In particular, our results suggest a link between traffic and asthma. At present, it is not possible to distinguish the role played by the aerosols from the role played by the precursor gases since both will be higher near the traffic source.

The seasonal cycle of asthma (winter maximum) combined with the small seasonal variation in nitrogen oxides and the larger seasonal variation in particulate nitrate fraction is suggestive of a particulate role. Further research will be required to better separate the effects of the aerosols and their precursor gases.

The global pattern of asthma provides an ideal means to further examine the relationship between asthma and pollution. The high prevalence of asthma in New Zealand and Australia provides a means to examine the seasonal dependence of asthma. Recently published results indicate that asthma hospitalizations peak there during Northern Hemisphere summer (Southern Hemisphere winter) reinforcing the notion that the seasonal change in aerosol type is responsible.

The asthma survey revealed a number of interesting new findings. Chief among these is that the prevalence of asthma is highest in Manhattan. Like previous investigations of asthma, our results reveal racial differences in the prevalence of asthma. This result is interesting since we do not find a relation between socio-economic indicators and asthma prevalence. Thus, this racial difference is not due to socio-economic factors, but could be due to racial differences in the proximity of traffic.

The higher prevalence of asthma in our survey is consistent with previously published surveys that find elevated asthma rates in urban centers. This spatial pattern again suggests an environmental component.

Our analysis of the representativeness of our socioeconomic proxies (type of school lunch and type of medical care) revealed that these are valid indicators of socioeconomic status (i.e., highly correlated with income). Moreover, this investigation showed that the type of medical care is also strongly correlated with income. Thus, previous investigations of the prevalence and spatial distribution of asthma that are based on hospitalization data are biased as they underreport the prevalence of asthma in higher income communities. This has important implications for policy. Since our results indicate that asthma may be more related to urban living (proximity to pollution) than availability of medical care. Moreover, while aerosols and their gaseous precursors have a relatively short lifetime, they can still be transported over significant distances. Thus, aerosols or their precursors transported from Philadelphia and Camden may be responsible for the higher than expected prevalence of asthma in southern New Jersey (Ocean and Monmouth Counties).

Our finding that the majority of asthma sufferers also have allergies provides a mechanism through which pollution can influence both the severity and frequency of asthma attacks. Moreover, the threshold-type relationship between NO2 and allergic reaction could also be driving the global increase in allergy.

The strong connection between aerosols, aerosol precursors and asthma argues for stronger regulations limiting the production of secondary aerosols. However, since these aerosols produce a climate cooling, decreasing their concentration will further amplify climate warming. Moreover, the difference in the residence time between aerosols and greenhouse gases suggests that while regulations to limit aerosols will have an instantaneous effect on climate reductions in the greenhouse gases would take longer to be felt. This increases the importance of the possibility of decreasing black carbon emission at the same time as the sulfates and nitrates are reduced, since black carbon aerosols (soot) produce a warming.

Ironically, the clean air act has shifted the chemistry of the atmosphere. By decreasing the emission of primary aerosols, it is resulted in an increase in secondary aerosols. These aerosols are generally smaller and more readily inhaled. This change in the chemistry of the aerosol (pollution) in "cleaner" areas is seen in investigations of East vs. West Germany. Immediately following unification, studies found that asthma was more prevalent in West Germany while bronchitis was more prevalent in East Germany. With unifcation and additional time, the prevalence of asthma in East Germany is increasing.

How ICP Summer Research can Improve Teaching

I teach Regent's physics at the Frederick Douglass Academy (FDA) in Harlem and joined ICP's asthma and aerosol team this summer. My project focused on determining the reliability of hand-held sunphotometers by comparing their optical depth measurements to those from NASA's CIMEL instrument.

During the academic year, I expect to continue testing the hand-held instruments to refine their use. I would like to design a small study to determine if measurements made over a wide air-mass range give more accurate optical depths. I will recruit a few students to help with the investigation.

I would also like to use the sunphotometers in a laboratory exercise because it could help reinforce concepts and skills needed for the Regent's exam. Understanding how a sunphotometer works when measuring incident voltages helps reinforce physics concepts like: light is energy, the electromagnetic spectrum is a range of wavelengths, and objects can scatter and refract light. Calculating optical depths using Langley Regression helps strengthen graphing skills needed for the Regent's exam, which requires students to use a line's slope and intercept to gain information.

I hope to use the summer's writing workshops as a model to develop my students' writing skills. The worksheet questions for the introduction and methods sections of the research paper helped clarify ideas. I expect to use the same type of questions to help me evaluate how well my students understanding physics concepts. I also expect to use the "event-V", introduced by Robert Crockenberg, to guide my students through writing a research paper. I see them writing two papers. The first paper will be based on a classroom activity that imitates a science experiment- like investigating patterns in paper passing (Appendix A). The second paper will be based on an in-class research experiment; I am still searching for an appropriate activity.

Finally, the summer ICP experience provides a foundation for the FDA Research Society, which I hope to initiate this year (Appendix B). I hope to use the Research Society to prepare students for research internships. The research performed by students sets an example and establishes expectations for incoming students. Participating in the research gave me first-hand knowledge of the skills students need to develop before entering a program, like using Excel, graphing line graphs and histograms, and performing statistical analysis like averages, percents, and standard deviations. Using the ICP summer research allows me to provide an example where these research skills are needed; this will help me motivate my students to prepare well.

Appendix A

Classroom Activity that Models a Scientific Investigation

This activity provides a simple investigation that involves students and gives an easy example for writing for writing the introduction, methods, results, and discussion sections for a research paper. It also can be used to show how a “V” diagram can help organize ideas.

The questions being investigated are:

1. Do long times for passing the cards create a more even distribution?
2. Do cards distributed to higher densities of students have more marks on them, are they passed more often.

Protocol:

- Stand in the center of a classroom
- Distribute 10 square shaped cards, half of an index card works well.
- Give only one card per person.
- Each student makes a tally mark on the card they just received, then passes the card to someone else.
- Allow the passing to continue for a few minutes.
- Stop the passing and have each person mark the location of the card in the classroom.
- Repeat the process for a new set of cards and vary the time allowed for passing.

Using the “V” diagram

Questions:
1. Do long times for passing the cards create a more even distribution?
2. Do cards distributed to higher densities of students have more marks on them, are they passed more often.

Concepts

Theories, Principles, Ideas:

Starting from one point, the cards should spread out.

Areas with more students will see more trading.

Methods

Data, Transformations, Claims:

Make the classroom seats into a Cartesian grid; each seat has a location, like A3.

When the passing time has ended, mark each card's location on the grid and record the number of tally marks.

Analyze the data to make claims about the distribution of cards and tally marks.

Event:
10 cards are distributed from one location; each time a card is passed a tally-mark is added to the card.

Appendix B

FDA Research Society

Purpose:

Motivate students to pursue scientific research by introducing different fields of study; prepare students by developing research skills.

Format:

Students attend weekly after school sessions.

Tasks:

Introduce Current Scientific Research:

Use articles from newspapers, popular magazines, science magazines, and science journals, stimulate interest and knowledge of current research

Research Skills

Provide activities that develop skills using spreadsheets, analyzing data, writing, etc.

Analyze data sets that have already been used in research.

Design experiments that require collecting, analyzing, and publishing results.

Internships

Identify and apply to science internships.

Creative Thinking

Most students lack the creative thinking required for research. Games magazine puzzles, MIT inspired projects, math challenges, etc., can be used to improve creativity and critical thinking skills.

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