**COLLEGE OF CHARLESTON**
**FACULTY RESEARCH AND DEVELOPMENT COMMITTEE**
**GRANT APPLICATION COVER SHEET**

(Deadlines are 5:00 pm on the dates shown below. Submit the complete grant application electronically to the Chair of the Faculty R & D Committee. Submit the cover sheet signed and dated to the Dean of the Graduate School by the 5:00 pm deadline.)

[✓] First Round (10/01/10) [ ] Second Round* (01/21/11) [ ] Third Round (04/01/11)

NAME: Michael L. Larsen RANK: Assistant Professor

DEPARTMENT: Physics and Astronomy PHONE: 843-953-2128

PROPOSAL TITLE: Turbulent Mixing of Aerosols

*In which fiscal year will your project take place? [ ] FY 10-11 [ ] FY 11-12

Please refer to the Guidelines to insure that you comply with conditions for the category of award you seek.
A copy of the guidelines may be found at the Faculty and Staff Resources link at
www.cofc.edu/graduateschool/facultystaff/index.php

**Which category of award do you seek? (Check one)**

[✓] Faculty Research Grant [ ] Faculty Development Grant [ ] Faculty Professional Support

**Check all sub-categories that apply.**

[✓] Starter Grant (Check if the period of the grant is during your tenure-track appointment as a faculty member at the College of Charleston and your proposal meets the Starter Grant criteria.)

[ ] Teacher-Scholar Grant (Check if your proposal meets the Teacher-Scholar Grant criteria..)

[ ] Continuous Study Award (Check if your proposal meets the Continuous Study Award criteria.)

**Total Amount requested? $** $3,310.00

**Have you received Faculty R & D support for a funding period in the calendar year 2010?**
**(Yes/No)** NO **(If yes, list the amounts and dates in the spaces below)**

**Do you expect to receive funds from any other source for this project?**
**(Yes/No)** NO **(If yes, list the sources(s) and amount(s) of the funding below)**

**Does the proposal involve research on human or vertebrate animal subjects? (Yes/No)** NO
**(If yes, include a brief statement describing the status of the Institutional Review Board (IRB) and/or Institutional Animal Care and Use Committee (IACUC) application. Such an approval must be obtained before research and development funds can be released.)**

SIGNATURE, Applicant [signature] Date 9/23/10

**Department Chair/Dean: Funds for successful proposals will be transferred into the departmental R & D account.**

SIGNATURE, Department Chair/Dean [signature] Date 9/23/2010

**Turbulent Mixing of Aerosols**
**Michael L. Larsen**
**Faculty Research and Development Committee Grant Proposal**
**Fall 2010**

# Project Summary

The process of aerosol particulate mixing on scales relevant to atmospheric processes and biological organisms (smaller than a breadbox) is poorly characterized. Until relatively recently, it was widely assumed that since aerosol particles have low masses compared to everyday objects that they mix in turbulent flows as "passive scalars" (or, in other words, they are moved about freely by any air flows).

Although aerosol particles are light, they do carry mass and therefore have an inertia associated with them. Recent studies (by the PI and other investigators) have revealed that turbulent motions do a great deal to quickly mix aerosols with ambient air, but ultimately turbulent mixing is "quick but not thorough". Since turbulence itself is a correlated forcing mechanism (it is random, but with statistical structure), it has become apparent that the aerosol particles maintain some sort of statistical spatial structure even after being exposed to a turbulent flow for a very long time (perhaps indefinitely).

Although this statistical structure may not be evident macroscopically, understanding of the statistical structure of the aerosol spatial distribution could allow for a more complete understanding of microphysical atmospheric processes like activation (the process of going from an aerosol particle to a cloud droplet), the distribution of vapor within a cloud, or modeling dose-response relations for large airborne pathogens (where distributions over small physical domains becomes important and the notion of a macroscopic concentration can break down).

In this work, the PI proposes to investigate this structure experimentally through the use of modified commercially available aerosol counters.

## Itemized Budget

| Item | Requested from FRD | Startup Match | Total |
|---|---|---|---|
| CLiMET Particle Counters | $0 | $3000 | $3000 |
| Calibration Microspheres | $900 | $900 | $1800 |
| TDS2004B Digital Storage Oscilloscope | $2160 | $0 | $2160 |
| LabView Software | $0 | $700 | $700 |
| MATLAB software | $0 | $2400 | $2400 |
| NI Acquisition Hardware | $0 | $1000 | $1000 |
| TSI Nebulizer | $0 | $720 | $720 |
| Royco Nebulizer | $0 | $350 | $350 |
| Young 81000 Ultrasonic Anemometer | $0 | $2400 | $2400 |
| Data Acquisition Computer | $0 | $2000 | $2000 |
| Student Worker | $250 | $0 | $250 |
| TOTALS | $3310 | $13470 | $16780 |

### Item Justification

- CLiMET Particle Counters – The instruments that take the necessary aerosol data. Additional repair costs will be taken from PI startup funds.
- Calibration Microspheres – In order to calibrate the particle counters, known particle sizes have to be fed through after instrument modification. These calibration microspheres allow for doing this with a known particle size. Enough money is budgeted to get a 8 point calibration curve ranging from nominally 0.5 micron to 20 micron particle sizes. To satisfy the needs of this project, approximately twice the number of microspheres will be necessary than the PI budgeted out of his original startup budget.
- TDS2004B Digital Storage Oscilloscope – Necessary in order to bench test/verify acquisition code. (Manual check of code as well as transducer testing). Not budgeted for in startup, as this equipment was not needed for other projects planned by PI.
- LabView/MATLAB Software/ NI Hardware/ Nebulizers / Ultrasonic Anemometer / Data Acquisition Computer – Vital equipment to this and other projects, pre-purchased from start-up costs. Necessary for data acquisition and analysis.
- Student Worker – Requested for 25 hours of labor at $10/hr in order to help fix particle counter and help with calibration process.

## Introduction/Overview

Mixing of particles in the free atmosphere is principally governed by two processes – turbulent mixing (sometimes called turbulent diffusion) and "standard" diffusion. For aerosols (suspended liquid or solid particulates in air), standard diffusion processes are extremely slow due to the relatively large masses of the suspended particles. (The masses may be in the sub-micro-gram range, but that is still many orders of magnitude heavier than gas molecule masses.) Because of this, mixing processes in turbulent environments are governed by turbulent diffusion.

Turbulent diffusion – like most problems associated with turbulence – is mathematically challenging. However, understanding turbulent processes in a statistical sense can be tractable. We know from previous experimental studies that turbulent diffusion of aerosols is "quick but not thorough". An easy way to envision this is to imagine making chocolate chip cookie dough; after adding the chocolate chips, it only takes a few strokes of the mixing spoon to move the chips throughout the entire dough; however, you can continue stirring for a very long time until you cease to see little pockets of chips close together. In the case of cookies, one way to help mix the chips more efficiently is to add the chips gradually while stirring; the aerosol analog of this is to introduce the particles into the air gradually. However, there are many scenarios where all of the particles are added suddenly to the atmosphere (e.g. like opening an anthrax filled envelope or – a much more benign case – clapping an eraser in a room).

Here, I propose an experimental investigation into the nature of how these aerosols mix in indoor turbulent air when added suddenly to an environment. It has become apparent from other studies over the last half-decade that rather sophisticated statistical analysis of aerosol concentrations must be done to make risk assessment for airborne pathogens – not only do we need to know how many pathogens exist in the air, but the detailed structure of how they clump together in rather small volumes ends up relevant to a physical model for risk assessment. The nature of these investigations need not include actual respiratory processes (which we can simulate) nor the use of pathogenic airborne particulates. The meaningful science can be done with a modified aerosol particle counter and benign particulates like chalk dust or (most commonly) aerosolized polystyrene latex spheres.

My goal is to investigate the detailed spatio-temporal scale dependent statistics of how clustered aerosols introduced into a closed room mix over time. I plan to use modified commercially available particle counters (recalibrated and modified for MHz response rates) to obtain a detailed statistical picture of the "clumpiness" of the particles in the air as a function of elapsed time, size of the particulate, and intensity of the ambient turbulence.

**Objectives/Timeline**

| | |
|---|---|
| Jan/Feb | Obtain and modify commercially available particle counters to use a reduced flow (0.01 cfm) flow rate (pseudo-ambient sampling) and record aerosol arrivals to 1 MHz precision. |
| Feb/March | Manually recalibrate particle counters to obtain particle size as a function of transducer voltage for modified flow rates. |
| March/April | Write software (in LabView) to automate data acq. at 1 Mhz. Write software (in MATLAB) to infer from data a time-series of aerosol particle arrivals. |
| April/May | Design and conduct experiments measuring the pair-correlation function as a function of elapsed time, particle size, and turbulence strength (characterized by dissipation rate $\epsilon$). |
| May/June | Conduct data-analysis on experimental results to develop preliminary conclusions. Write and submit final report. |
| June/July/Aug | Prepare peer-reviewed manuscript for submission. Prepare proposal for extramural funding. |

**Methodology/Work Plan**

Following the timeline presented above, the first task will be to acquire suitable commercial instruments to handle the particle counting. The PI has done this same type of experiment previously, but has changed institutions and will need to acquire at least one new instrument to complement the counters already in the lab. After acquiring these counters, they will need to be modified to have approximately 1/100th their original flow rate. This is necessary because we want to be sampling the ambient statistics for aerosols in the room, and the counters – as natively constructed – actually generate internal turbulence far in excess of what occurs in the room. (Reynolds numbers inside the instrument exceed $3 \times 10^5$.) By modifying for slower flow-rate, we can move the flow inside the instrument to be laminar and not overly disturb the ambient statistics.

The second, labor-intensive part of the work will be recalibrating these devices for slower flow rates. These instruments use white-light scattering onto a photo-detector to infer particle size; the larger and longer the voltage pulse, the larger the particle. With a lower flow rate, the internal electronics will read every particle as being substantially larger (orders of magnitude) than the actual particle size. This can be recalibrated by hand if we use the transducer output directly and place particles of known size into the device; by looking at the voltage pulses that result from the particles of known size, we can develop an empirical recalibration at the lower flow rate. Though this step is straightforward (and I may enlist a student to help me with this), the process is lengthy and tedious – but entirely necessary to complete the goals of the project.

The next step is to write codes to acquire data at high temporal resolution and infer from this data a time-series of aerosol arrivals at the particle detector. The explicit statistical use of the pair-correlation function and the interest in small distances (which are relevant to the theoretical problem) mandates that this be done with the fastest acquisition available; the PI has purchased (through start-up monies) a 1 MHz acquisition card that should enable this to be done with sufficient resolution. The code to acquire this data and process it will be modified from previous code the PI has written for a similar (though different) application with a different type of probe.

Finally, the experiments can be carried out. The PI's laboratory (RHSC 303b) is ideally designed for a simple experiment of this type, with dimensions approximately equal to the injection scale. A known, benign aerosol (either chalk or candle smoke) will be used in conjunction with commercial fans to develop a well-defined eddy that should dissipate with an easily calculated dissipation rate within the room. To obtain meaningful measurements of dissipation rate, the PI will set up his 3-d sonic anemometer in the room to obtain turbulence statistics. The aerosol counter will be placed nearby to obtain the necessary data for the statistical study.

The data acquired from the experiments should allow for meaningful examination of the nature of mixing as a function of time. The pair-correlation function, and – if necessary – fractal box-counting and/or power-spectral analysis (perhaps resorting to wavelets due to the statistically inhomogeneous nature of the data) will be utilized in order to characterize the mixing properties. The final project report and subsequent major extramural funding application and peer-reviewed article will then be constructed after the formal end of the project date.

### Research Significance

Despite a voluminous amount of work that has been done on turbulent mixing, the work I propose to do here is fundamentally different from the work typically done elsewhere. The details are rather technical, but I plan to use the pair-correlation function to quantify deviations from pure randomness in a scale-invariant way. Most studies phrase this work in terms of concentration fluctuations, which presupposed a fundamental volume of interest. As there are several relevant scales to air pathogen modeling (mean-free-path to internal biological contact, tidal volume of breath, diffusion distance during a single breath), it is the PI's stance that a scale-invariant way of characterizing the statistical fluctuations is most appropriate. Unfortunately, this requires data to be recorded in a way that usually is not done and necessitates the taking of brand new data in the PI's own lab. However, if the results come out as expected, this investigation could open up an entirely new way of modeling airborne pathogen infectivity beyond that standard logistic equation based on a physically motivated transport model.

### Professional Development Significance

The PI is in his first semester as a tenure-track faculty member at the College of Charleston. Funding for this project would greatly help the PI's ability to persue competitive external funding on this question. (The results from this study should provide excellent preliminary results to demonstrate the feasibility of a more substantial externally funded project.) This work also will support student research to computationally model airborne pathogen received dosages in biological organisms; the experimental results from this work can be used as input model parameters for this student's computer model. Finally, this project helps to open up a new subfield that the PI has not previously published in while complementing in a natural way the rest of his ongoing research program.

### Dissemination Plan

This work should become the backbone of an extramural grant proposal to be submitted sometime in summer or fall 2011. Apart from that dissemination, the PI has a long history of using his experimental results to publish in appropriate topical journals. For this work, the publication "Journal of Aerosol Science" (where the PI has previously published and has reviewed for) seems most appropriate. A peer-reviewed manuscript is likely to be submitted sometime in the summer to this journal based on this work. Additionally, if the results merit it, the PI may submit an abstract for presentation at the next AAAR (American Association for Aerosol Research) meeting.

# IRB/IACUC

Although there are applications of this work eventually to biological applications, there is no portion of this project that will involve animal or human experimentation and, as such, IRB/IACUC approval is not necessary.

Michael L. Larsen, Ph.D.
LarsenML@cofc.edu

Phone: (843) 953-2128
Fax: (843) 953-4824

Assistant Professor
College of Charleston
Department of Physics and Astronomy
310 Rita Liddy Hollings Science Center
58 Coming Street
Charleston, SC 29424

---

## Education

- Doctor of Philosophy (Physics), August 2006
  Department of Physics, Michigan Technological University, Houghton, MI
  Thesis title: Studies of Discrete Fluctuations in Atmospheric Phenomena
  Thesis advisor: Dr. Alexander B. Kostinski
  Graduate GPA : 3.88

- Bachelor of Science (Physics), May 2001
  Department of Physics, Michigan Technological University, Houghton, MI
  GPA : 3.95 / Graduated *summa cum laude*

## Professional Employment

- Assistant Professor, August 2010 - Present
  Department of Physics and Astronomy
  College of Charleston, Charleston, SC

- Assistant Professor, August 2007 - August 2010
  Department of Physics and Physical Science
  University of Nebraska at Kearney, Kearney, NE

- Consultant, August 2007 - August 2009
  Army Research Laboratory, Adelphi, MD

- National Research Council Postdoctoral Fellow, July 2006 - July 2007
  Army Research Laboratory, Adelphi, MD
  Funded Proposal: Analysis of the Role of Number Fluctuations in an Apparatus to Detect Hazardous Airborne Particles

- National Defense Science and Engineering Graduate Fellow, August 2003 - July 2006
  Sponsored by the DoD, Managed by ASEE

- Graduate Researcher in GSSP Summer Program, June 2003 - August 2003
  NASA-Goddard Earth Science and Technology Center
  Goddard Space Flight Center, Greenbelt, MD

- Graduate Research Assistant, June 2002-August 2003
  Graduate Fellow, January-June 2002
  Department of Physics
  Michigan Technological University, Houghton, MI

## Current Main Research Interests

- Radiative transfer through statistically correlated random media (cloudy atmospheres)
- Effects of finite sampling and dead-time on statistical inference
- $Z - R$ relationships in radar meteorology
- Fluctuations of aerosol particles, cloud droplets, and raindrops – quantification and applications
- Accounting for natural variability in airborne pathogen risk estimation
- Simple Monte-Carlo models for discrete spatial systems
- Environmental Radiation

## Funding Awarded – Last 5 Years

- Research Corporation Cottrell College Science Award (2011-2012)
- NASA Nebraska Space Grant Minigrants (2009, 2010) NASA Nebraska student fellowships (2009, 2010), and NASA Nebraska Travel Grant (2009)
- Program of Excellence Funds for a 3D-Ultrasonic Anemometer (2009)
- Focused Assessment Grant (2008-2009)
- University of Nebraska at Kearney Research Services Council (UNK RSC) University Research and Creative Activity grant (2008-2009) and Minigrant (2008)
- National Research Council Postdoctoral Fellowship (NRC) (2006)
- National Defense Science and Engineering Graduate Fellowship (NDSEG) (2003-2006)

## Professional Activities

- Serves as peer-reviewer for: *Aerosol Science and Technology*, *Applied Spectroscopy*, *Geophysical Research Letters*, *Journal of Applied Meteorology and Climatology*, *Journal of Atmospheric and Oceanic Technology*, *Journal of Hydrology*, *Journal of the Atmospheric Sciences*, *Nonlinear Processes in Geophysics*, *Quarterly Journal of Spectroscopy and Radiative Transfer*, National Science Foundation

- Courses Taught: Atmospheric Physics (F2010), Computers in Physics (S2010), Earth Science/Honors Earth Science (F2007, F2008, S2009, F2009, S2010), General Physics II Lab (F2010), Introductory Physics II (F2010), Meteorology (S2008, S2009, S2010), Modern Physics (F2009), Physical Science (F2007, S2008, F2008, S2009), Special Topics in Physics – Qualitative Reasoning in Physics (S2009, F2009), Research in Physics (S2008, F2008, S2009, F2009, S2010)

- Current and former undergraduate research mentees: Tobin Barrett, Josh Beck, Phil Boehner, Dawn Carrillo, Jose Carrillo, Benjamin Fullerton, Kenny Galusha, David Hayes, Kyle McClary né Smydra, Joshua Moravec, Matt Noffke, Danielle Policarpio, Grant Saltzgaber, Adrian Sanabria-Diaz, Cameron Self, Jenn Smaroff, Aaron Steele, Jeremy Stromer

## Peer-Reviewed Publications

- Identifying the Scaling Properties of Rainfall Accumulation as Measured by a Tipping-Bucket Rain Gauge Network
  M.L. Larsen, A. Clark, M. Noffke, G. Saltzgaber, and A. Steele
  *Atmospheric Research, 96*, 149-158 (2010).

- Simple Dead-Time Corrections for Discrete Time Series of Non-Poisson Data
  M.L. Larsen and A.B. Kostinski
  *Measurement Science and Technology, 20*, 095101 (2009).

- Spatial Distributions of Aerosol Particles: Investigation of the Poisson Assumption
  M.L. Larsen
  *Journal of Aerosol Science, 38* (8), 807-822 (2007).

- The Texture of Rain: Exploring Stochastic Micro-structure at Small Scales
  A.B. Kostinski, M.L. Larsen, and A.R. Jameson
  *Journal of Hydrology, 328* (1-2), 38-45 (2006).

- Observation and Analysis of Steady Rain
  M.L. Larsen, A.B. Kostinski, and A. Tokay
  *Journal of the Atmospheric Sciences, 62* (11), 4071-4083 (2005).

- Small-scale Drop Size Variability: Impact on Estimation of Cloud Optical Properties
  Y. Knyazikhin, A. Marshak, M.L. Larsen, W.J. Wiscombe, J.V. Martonchik, and R.B. Myneni
  *Journal of the Atmospheric Sciences, 62* (7), 2555-256 (2005).

- Small-scale Drop Size Variability: Empirical Models for Drop Size-Dependent Clustering in Clouds
  A. Marshak, Y. Knyazikhin, M.L. Larsen, and W.J. Wiscombe
  *Journal of the Atmospheric Sciences, 62* (2), 551-558 (2005).

- Response from Authors to Comment on Detection of Spatial Correlations among Aerosol Particles
  M.L. Larsen, W. Cantrell, A.B. Kostinski, and J. Kannosto
  *Aerosol Science and Technology, 38* (2), 129-130 (2004).

- Detection of Spatial Correlations among Aerosol Particles
  M.L. Larsen, W. Cantrell, J. Kannosto, and A.B. Kostinski
  *Aerosol Science and Technology, 37* (6), 476-485 (2003).

- Towards Quanifying Droplet Clustering in Clouds
  R.A. Shaw, A.B. Kostinski, and M.L. Larsen
  *Quarterly Journal of the Royal Meteorological Society, 128* (582), 1043-1057 (2002).

## (Nonreviewed) Books

- Discrete Fluctuations in Atmospheric Science
  M.L. Larsen
  218 pp., VDM Verlag Dr. Mueller e.K. (2008).

- Investigations in Earth Science
  M.L. Larsen
  160 pp., Published In-House by UNK (2008).
  2nd Ed. 183 pp., Published In-House by UNK (2009).

## Conference Presentations

- Development of a Ballistic Photon Transport Model that Explicitly Resolves Cloud Microstructure
  M.L. Larsen, A. Clark, A. Steele, and D. Hayes. *13th AMS Conference on Cloud Physics, jointly with 11th AMS Conference on Atmospheric Radiation.* Portland, OR. 28 June - 3 July, 2010.

- Affordable Ways of Measuring Rain One Drop at a Time
  M.L. Larsen. *120th Annual Meeting of the Nebraska Academy of Sciences.* Nebraska Wesleyan University. Lincoln, NE. 23 April 2010.

- Examination of Sub-Pixel Accumulation Variability in Central Nebraska
  M.L. Larsen, A. Clark, M. Noffke, G. Saltzgaber, and A. Steele. *34th Conference on Radar Meteorology.* Williamsburg, VA. 5-9 October, 2009.

- Direct Simulation of Radiative Transfer through a 3-Dimensional Correlated Medium
  M.L. Larsen, A. Clark, and A. Steele. *Gordon Research Conference on Radiation and Climate.* Colby-Sawyer College, New London, NH. 5-10 July, 2009.

- Developing an Undergrad Research Program from Scratch: Perspective from Two Physicists
  M.L. Larsen and L. Kreminska. *Research at Primarily Undergraduate Institutions.* Kearney, NE. 6 March, 2009.

- Unresolved Small-Scale Optical Variability of Clouds: Two Ways of Assessing its Impact on Remote Sensing Observations and Energy Budget Estimations
  A.B. Davis, M.L. Larsen, and K. Pfeilsticker. *2006 Fall AGU Meeting.* San Francisco, CA. 11-15 December, 2006.

- A New Model of Spatial Cloud Drop Distribution that Simulates the Observed Drop Clustering: Effect of clustering in Extinction Coefficient Estimates
  A. Marshak, Y. Knyazikhin, M. L. Larsen, and W. Wiscombe. *2006 Fall AGU Meeting.* San Francisco, CA. 11-15 December, 2006.

- Impact of Unresolved, Correlated, or Anti-Correlated Spatial Structure on the Bulk Transport of Radiation Inside and Between Clouds, with Applications to Remote Sensing and Energy Budgeting
  A.B. Davis, M.L. Larsen, and M.K. Dubey. *2nd International Conference on Global Warming and the Next Ice Age.* Sante Fe, New Mexico. 17-21 July, 2006.

- A New Model of Cloud Drop Distribution that Simulates the Observed Drop Clustering: Effects of Clustering on Extinction Coefficient Estimates
  Y. Knyazikhin, A. Marshak, M.L. Larsen, and W.J. Wiscombe. *16th Annual Meeting of the ARM Science Team.* Albuquerque, New Mexico. 27-31 March, 2006.

- Reconsideration of Certain Aspects of the Z-R Problem
  M.L. Larsen and A.B. Kostinski. *14th International Conference on Cloud Physics and Precipitation – ICCP 2004.* Bologna, Italy. 13-18 July, 2004.

- Exploring the Stochastic Micro-structure of Rain: Scale Dependence of Spatial Correlations
  A.B. Kostinski, A.R. Jameson, and M.L. Larsen. *17th Conference on Hydrology. 83rd Annual Meeting of the American Meteorological Society.* Long Beach, California. 9-13 February, 2003.

- Spatial Correlations among Aerosol Particles
  W. Cantrell, A.B. Kostinski, M.L. Larsen, and D. Harrington. *2002 Fall Meeting of the American Geophysical Union.* San Francisco, California. 6-10 December, 2002.

- Stochastic Micro-structure of Rain and Scale Dependence of Spatial Correlations
  A.B. Kostinski, A.R. Jameson, and M.L. Larsen. *2002 Fall Meeting of the American Geophysical Union.* San Francisco, California. 6-10 December, 2002.

- Possible Implications of Droplet Clustering for Radiative Transfer in Clouds
  A.B. Kostinski, M.L. Larsen, and R.A. Shaw. *11th AMS Conference on Cloud Physics, jointly with 11th AMS Conference on Atmospheric Radiation.* Ogden, Utah. 3-7 June, 2002.

- Quantifying Droplet Clustering in Clouds
  M.L. Larsen, A.B. Kostinski, and R.A. Shaw. *11th AMS Conference on Cloud Physics.* Ogden, Utah. 3-7 June, 2002.

- 27 Additional Presentations by Undergraduate Mentees at Various Venues (2007-2010)