The Biophysicist

Report on *BASICS: Lesson Plan on Aerosols and Infection*

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Introduction

From online lectures to virtual lab assignments to Zoom breakout rooms, COVID-19 has changed the way students are learning around the world. The goal of the *BASICS: Lesson Plan on Aerosols & Infection* is to help students understand the biophysics underlying aerosols to explain why the SARS-CoV-2 virus has taken over our lives. The Lesson Plan explains how aerosols travel through air and demonstrates how masks can effectively prevent aerosol transmission and, by extension, viral infection. In this Report, we discuss how we developed this Lesson Plan and what students can learn about infectious virus spread in relation to aerosols.

Experiment development

The Biophysical Society *BASICS: Biophysics—A Step-by-Step Introduction to Concepts for Students* (1) series of lesson plans is intended to introduce biophysical concepts to high school teachers and students. In developing the lesson plan on aerosols and infection (see Supplemental Material), we assessed the movement of aerosols through the air. We used a fragrance atomizer to produce an aerosol and designed experiments to demonstrate how aerosolized droplets fall onto a surface or travel different distances by convection, and spread out by diffusion. We tested the distribution of aerosol droplets when produced at 3 and 9 inches from a surface, but we encourage students to try different distances to get a sense of how changes in distance affect the distribution of the droplets. We placed pieces of white paper horizontally and vertically to monitor the fall of colored water droplets onto a surface and travel of the droplets through air to see how they changed at different distances (Fig 1). A second experiment was designed to test a simple paper barrier in preventing aerosol transmission with a view to demonstrating how efficient masks are in preventing disease transmission. This experiment used an identical setup to the previous one, but a paper towel mask was affixed to the vertical piece of paper to determine if aerosol droplets could pass through the layers of the mask.

More advanced students could modify the experimental setup to test more in-depth experimental questions. For example, students could investigate the effect of airflow or fluid properties on droplet

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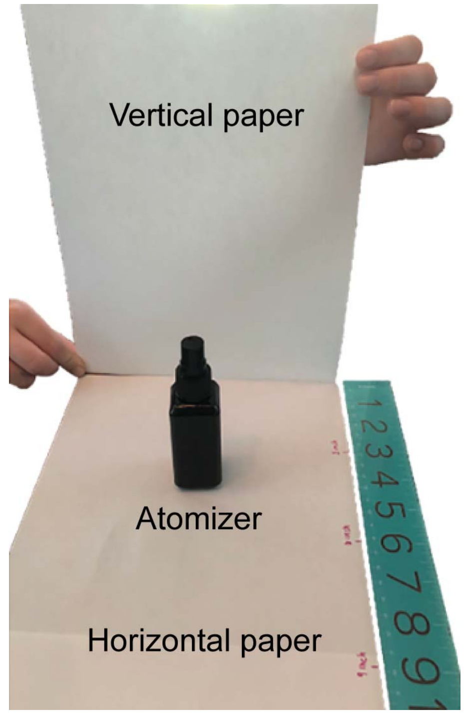

Fig 1. Experimental setup. An atomizer is placed on a horizontal sheet of paper at a given distance from a vertical sheet of paper. After spraying, the atomizer distance to the vertical sheet is changed and the paper is replaced with new sheets. Droplet distribution is analyzed on both sheets. Ruler at right. Reproduced from the Supplemental Material.

distribution by designing their own experiments to test these ideas. To change the airflow in the experiment, students could use a sheet of paper to fan the air in front of the atomizer while it was being sprayed or blow a mechanical fan on the atomizer during spraying to compare with the control condition. Alternatively, students could change the fluid density and viscosity by using a solution of 10%–20% sucrose or honey instead of water. The Notes section of our lesson plan (see Supplemental Material) explains how we estimated the diffusional spread of the aerosolized droplets and quantitated the size of the droplets that fell onto the horizontal paper by gravity. While developing these tests, we tried to design experiments to be informative for students while also teaching them how to reduce spread of infectious diseases that can be transmitted by aerosols, such as COVID-19.

Experimental results

The experiments allowed us to convey our understanding of aerosolized droplets and how they fall to surfaces because of gravity, travel by convection, and spread by diffusion. In the first experiment, we found that the distribution of dye spots on the vertical paper becomes larger by diffusional spread when the atomizer is farther away. We also saw an increase in the distribution of dye spots on the horizontal paper when the atomizer was moved farther away from the vertical paper, given that more droplets fall by gravity because their forward movement is slowed by air resistance. Quantitative analysis confirmed these results by demonstrating that the overall dye density values changed after the atomizer was moved farther away, indicating that more droplets had landed on the horizontal paper. The second experiment demonstrated that our paper towel mask prevented aerosol droplets from passing through—dye spots were not observed on the paper underneath the mask, although dye spots were on the mask and on the paper surrounding the mask. This was confirmed by quantitating the dye density on the paper, which showed that the paper before spraying (denoted "background") and the region covered by the mask after spraying had the same density values, indicating that the mask was highly effective in blocking the droplets from reaching the paper underneath. By extension, we took these results to mean that masks, if worn over the mouth and nose, would prevent droplets containing infectious particles from reaching these areas and being breathed in.

Key takeaways for lesson plan developers

Through the development of this lesson plan, we were able to demonstrate basic concepts about aerosolized droplets and their transmission. We applied image analysis methods to quantitate the fall of colored water droplets onto the horizontal paper and used quantification methods with controls to compare the results of the aerosol sprayed from different distances to the vertical paper. Additionally, we used accepted mathematical relationships to model diffusion and quantitate diffusion of aerosolized droplets and to estimate the effects of gravity on the droplets, and we confirmed our findings through repeated trials. We also confirmed the effectiveness of masks in preventing the transmission of aerosolized droplets. Most importantly, we developed new ways to demonstrate a scientific concept and teach others about our results. We developed this lesson plan with a view to making sure that our experiments would successfully teach concepts about aerosols and their biophysical properties. At the same time, we wanted to ensure that our experiments and explanations were simple enough for students to understand who are in the targeted age range of grades 6–12. Through step-by-step explanations of the procedures and results, we created a lesson plan that we believe can be understood by students in the targeted age range. In addition, we provide further information in the Notes section (see Supplemental Material) so that more advanced students can extend their knowledge by applying quantitative biophysical analysis to their experimental results.

Key takeaways for students

When students perform the experiments in this lesson plan, we hope they will learn the scientific method, including observation, experimental trials, and careful measurement. A key goal is that students learn how to analyze their data by qualitative observation, followed by quantitative methods to confirm their observations. Before performing the experiments, students should predict what they expect will happen when the aerosol is sprayed at different distances from the vertical sheet of paper and when the paper towel mask is sprayed. After the experiments have been completed, students should reflect on whether or not their predictions were correct. This will engage students in learning the concepts behind the experiments and teach them that experiments sometimes do not work as expected (2, 3).

The main learning objectives for this lesson plan include learning about how aerosolized droplets are transmitted and spread, gaining a better understanding of the scientific method, and improving data analysis and statistical skills. These learning objectives can be measured by how well students can explain what they learned at the end of the experiment. For younger students, the main objectives are to learn the scientific method by forming and testing a hypothesis. Older students who have had previous exposure to the scientific method will learn about statistics and droplet distribution by calculating the size of the droplets that remain suspended in air, the distance that droplets of different sizes spread in air by diffusion, the mass of droplets that fall because of gravity, and how quickly the droplets fall.

A major part of the scientific process is understanding why you may not get the results you expect and being able to explain what happened. Our intent is that students learn about aerosols and how they are transmitted through the procedures and analysis in our lesson plan and, by extension, how infectious diseases such as COVID-19 are transmitted. Furthermore, we hope this lesson plan will teach students to think critically about their experimental results, rather than simply accepting the results that we present in the lesson plan.

Conclusions

Our objective in developing this lesson plan was to convey biophysical concepts to students about aerosol transmission through air. An additional goal of the lesson plan was to demonstrate to students why masks are a simple but important way of preventing the spread of COVID-19 to protect themselves and their loved ones. The materials needed to perform the experiments in the lesson plan should be readily available to most or all students, and the procedures are sufficiently easy to be performed at home (as we did). We therefore encourage teachers to use this lesson plan for their students during virtual sessions throughout the current pandemic.

SUPPLEMENTAL MATERIAL

Supplemental material for the Hogewood and Endow 2020 *BASICS: Lesson Plan on Aerosols & Infection* is available at: https://doi.org/10.35459/tbp.2021.000176.s1.

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