HUMAN VENTILATION MODEL FOR MEDICAL SCHOOL STUDENTS

by

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ABSTRACT

Humans are complex beings that take in a variety of information in a variety of diverse ways. Understanding that every person processes information in a unique way is an important pathway in determining class structure and the method in which information is delivered to students. Students are typically multimodal learners but prefer certain learning methods over others. These include but are not limited to lectures, videos, reading, or having a hands-on experience. Professors can enhance the learning environment of their students by either tailoring their teaching method toward individual students, or by using a teaching method that acknowledges and uses each form of learning. The objective of this project is to develop a human ventilation model and corresponding video that can be used during the Case Application Session (CAS) within the Pulmonary Module at the TCU School of Medicine.

The concept of multimodal learning is described within the framework of medical school students learning the mechanics of human ventilation. The objective of this research project is to provide tools to assist students in learning the mechanics of human ventilation. Specifically, these tools include a video (visual and auditory learning) for students to view independently and a hands-on model with exercises (kinesthetic learning) for students to use within a team.

Acknowledgement-This work was supported by a SERC grant from the College of Science and Engineering at Texas Christian University, Tammy Pfrang, and David Yale.

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INTRODUCTION

In a world that desires comfortability and instantaneous gratification, technology has been revolutionized to meet the needs of all people across the globe. We have developed air conditioners to keep our house cool, airplanes to take us faraway places in a short amount of time, and the internet and cell phones to allow us to communicate with people we might not be in proximity with. Enhancements in agriculture have allowed individuals to leave the farming industry and pursue careers in the field of engineering to create new technology or the field of medicine to take these technological advancements and use them to provide better service and save lives. It begs the question; how do doctors know how to perform an open-heart surgery or cure someone's cancer? How do engineers know how to build the highways that we drive on every single day or design the components of the power plants used to provide the entire world with energy?

There certainly will always be unknown variables, which is an inevitable part of innovating, but the answer is that they receive an education that provides them with the fundamentals. Regardless of the kind of education they receive, it results in the accumulation of information and knowledge in their desired field of study. The key difference is how well that information is received and processed in the classroom.

There are several ways to create an environment that cultivates the maximum amount of learning. The first is to tailor to each individual person and use the learning method that best suits them. Although ideal, this can be difficult to be put into practice with large groups. The second is to choose a singular learning method and not consider the diverse ways the students in a group will learn. This will benefit those who prefer and learn best from that method but put those who do not learn that way at a disadvantage. The final and most beneficial option is to create a learning environment that is multimodal, allowing students to learn in their preferred method but also supplementing that learning with additional methods. In the age of the internet and especially after the COVID-19 pandemic, this final option has become more feasible. Professors can opt out of using a traditional classroom format and instead use the flipped classroom format allowing group discussions and hands-on opportunities to learn in the classroom. Material is provided through textbooks, online videos, and more. The goal of this project is simple – to create an educational tool that can provide multiple forms of learning to students.

This paper is a comprehensive outline of the creation of the model and how it represents the human ventilation system, the additional materials that are provided with the model in order to address the learning preferences of all students, and how the exercises in which the model is used help provide an understanding of the fundamental laws that govern human ventilation.

BACKGROUND

The Ventilation Process

Ventilation describes the process by which we move air into and out of the lungs for the purpose of gas exchange. The human body uses the contraction and relaxation of primary and assistant skeletal muscles. Although the contractions of the diaphragm provide most of the lung's volume change (approximately 58%), rib cage movement can contribute between 5% and 42% of the lung's total volume change [1]. First, it is important to define the important pressures that are typically measured in the human ventilation process, which are shown in Figure 1. The interpleural pressure is the pressure within the pleural space, which is between the visceral pleura lining in the lung and the parietal pleura lining the chest wall. Alveolar pressures are defined as the pressure within the alveoli or lung.

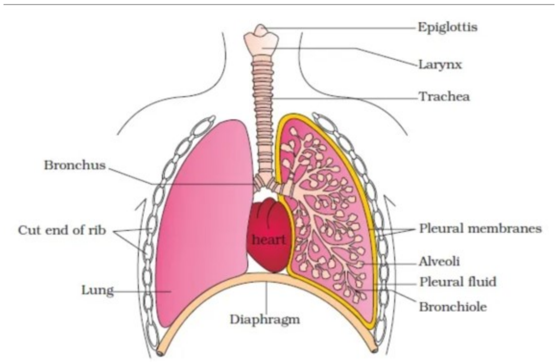

Figure 1: Human Anatomy for Ventilation Process
Courtesy of NCERT Book Class 11 Biology Chapter 17

Now, the two fundamental laws that govern the ventilation process can be defined: fluid flow along a pressure gradient and Boyle's Law, as shown in Figures 2 and 3. The flow of any substance, including gas, moves along a gradient from higher to lower pressure. Therefore, for air to flow into the lung during inspiration, the alveolar pressure must be lower than the pleural cavity that is at atmospheric pressure. In expiration, the alveolar pressure must be greater than the atmospheric pressure for air to exit the lung.

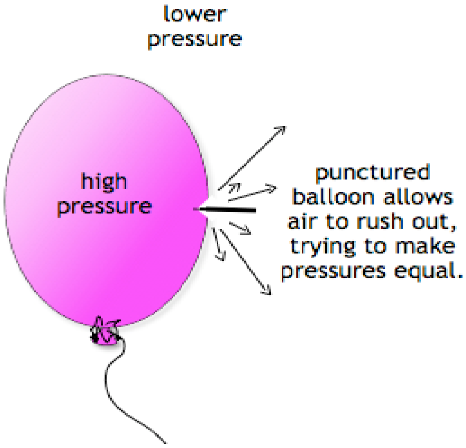

Figure 2: Fluid flow along a pressure gradient

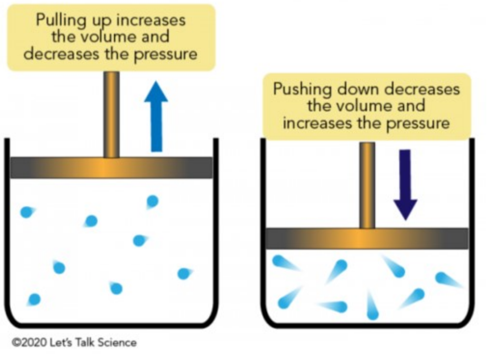

Figure 3: Boyle's Law
Courtesy of Let's Talk Science

The second law that governs ventilation, Boyle's Law, states that the volume of a gas is inversely proportional to the gas' pressure in a closed system [2]. As the volume of the closed system increases, the pressure decreases. As the volume of the closed system decreases, the pressure increases. As the diaphragm expands during inspiration, the pleural cavity volume increases and the pressure within the pleural cavity decreases. As the diaphragm relaxes during exhalation, the pleural cavity volume decreases and the pressure within the pleural cavity increases. The importance of intrapleural and alveolar pressures in the mechanics of ventilation can be highlighted through a comparison of pressures in the healthy state and the diseased state.

The Basis of the Project

The basis of this project is a paper published by Janelle Anderson et al., "Human Respiratory Mechanics Demonstration Model" (1). In this paper, the goal was to design and build a mechanical model that would improve student understanding of human respiratory mechanics. The aim was to develop a model that demonstrates pressure changes in alveolar and intrapleural spaces through the three-dimensional expansion of the thoracic cavity by the rib cage and diaphragm movement. This model developed in 2009 cost $430.41 and implemented two pressure sensors, but did not include the graphical display that shows the changes in pressures and the cost of the custom-built chamber.

In addition to physically testing the model, they also focused on what they deem the "most important aspect of the project," which was educational testing. A survey was administered to 427 students in Human Physiology 335 at the University of Wisconsin to determine if their learning improved with the use of the prototype. In the control group, the laboratory instructor gave a brief introduction that explained basic respiratory pressures and volumes. After the short lecture, students in the control group were given the post-survey on the concepts. In the experimental group, in addition to the brief introduction, the laboratory instructor gave the same introduction but also added a breathing demonstration using the model. Results showed that the control group and experimental group scored similarly on the pre-survey administered prior to the brief introduction and breathing demonstration. The post-survey scores were significantly higher in the experimental group than the control group, as shown in Figure 4.

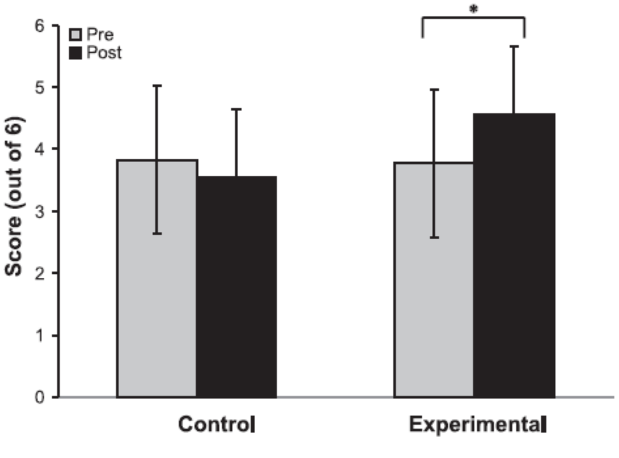

Figure 4: Pre and Post Survey Results- Human Physiology 355 at University of Wisconsin [1]
Control Group-Introduction Only
Experimental Group- Introduction and Breathing Demonstration with Model

Educational demonstration is a key aspect of implementing an educational tool in the classroom. This study supports the idea that every student learns in a different way and adding different forms of learning can often enhance their understanding of the material. Cofounding research and, in many instances, application of learning style theory has begotten the myriad of methods used to categorize learning styles of students. Once these learning styles are identified and understood, professors can attune to the needs of the students.

The Learning Styles

One of these methods that is used to categorize learning styles is the visual, auditory, reading, and kinesthetic model (VARK model), which is based on a 16-question survey that presents learning situations and asks the students how they would respond [3]. Visual learners are individuals that prefer to view information as drawings, diagrams, pictures, videos, and flowcharts. Auditory learners prefer to hear information be presented to them, primarily in the form of a lecture or video lecture. Reading/Writing learners prefer to see information in writing or textbooks. Lastly, kinesthetic learners prefer new information that is applicable to the real world or by using something that they can manipulate with their hands. In the VARK model, it is possible to have a strong preference of one learning style, in which case the individual would be deemed a unimodal learner. Respectively, they can also be recognized as bimodal, trimodal, and quadrimodal learners. Many individuals fall into the latter of being multimodal learners. In a study completed by Drago and Wagner, they found an indication that using more study strategies across all VARK categories was a successful method for improving course performance. Despite any statistical differences in studies across the board, the common point in all studies is that there are a variety of different learning styles. These include the ones that are described in this paper based on the VARK model, and the many others that have been developed, and it emphasizes the importance of employing different methods of teaching. This project addresses each of these four learning styles in some way, allowing for professors to create a more inclusive learning environment for students, whether students are fully aware of their preferences or not [3].

The Flipped Classroom

The flipped classroom maximizes the opportunity to incorporate different forms of learning into material and content for students. The core idea of the flipped classroom is to shift learning by transmitting information before class, in the form of instructional videos, recorded lectures, and textbook reading [4]. In turn, there is less time spent in class covering the basic concepts, allowing for the application of the material through complex problem solving, deeper conceptual coverage, and peer interaction in the classroom [4]. A study shows that more students in the flipped classroom prepared for class beforehand than those who attended traditional lectures, allowing students to spread out their workload and study throughout the course and customize or self-regulate the learning process to their personal needs and learning styles [4]. In a surgery clerkship, the flipped classroom approach was implemented, and many students agreed that they preferred the flipped classroom and their learning improved [5]. Our project can easily be incorporated into a flipped classroom, as a video is provided to watch in addition to lecture material assigned by professors, and the model is provided for use during the module.

THE PHYSICAL HUMAN VENTILATION MODEL

Several factors were considered when developing this model. The goal was to create a low-cost system that could be made of readily available materials, while also ensuring an accurate representation of the system that would benefit students in their understanding of material they have reviewed. A comparison of the model to the actual human system is shown in Figure 6. In total, one model costs approximately 350 USD, with the handheld graphical display and chamber included.

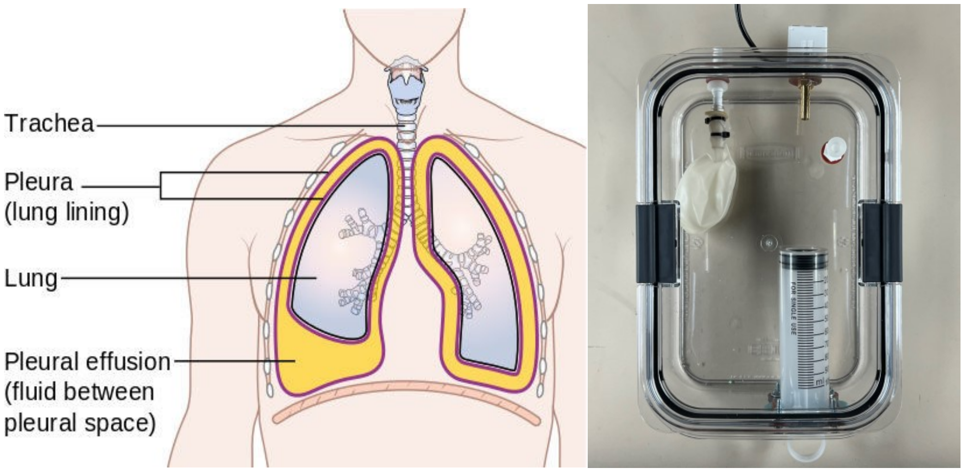

Figure 6: Side by side comparison of human system and model

The model consists of electrical components as well as mechanical components. The mechanical components of the model represent the system that facilitates the ventilation process. The electrical components facilitate the educational aspect of this project, allowing for the understanding of how interpleural pressure varies in a healthy state versus a diseased state.

The Mechanical Components

The mechanical components correspond to a specific part of the human ventilation system. The thoracic cavity itself in which the ventilation process takes place is represented by a transparent, plastic, air-tight container. Several considerations were made before selecting the 2.3 Liter Rubbermaid container that is used in the model. The container needed to be a transparent chamber so that students can see the system functioning as the diaphragm and rib cage were being manipulated. The air-tight container features a large opening with a thick rubber gasket and a 2-latch system. The container needed to be flexible enough that the rib cage movement could be simulated by squeezing. In addition, the container needed to be made of a material that was machinable so that a hole could be made for the syringe to be inserted in the container that models the pleural cavity. The final factor considered was that it needed to be large enough to fit all the components and create the most accurate representation, while also being robust enough that the model could be held in the hands of a student and not require excessive effort to use.

The other components of the model include the balloon that represents the lung, a Nalgene polypropylene barbed bulkhead fitting (6.5 mm) that represents the trachea, and the 1 3/8th inch syringe that represents the diaphragm as shown in Figure 7. The Nalgene polypropylene barbed bulkhead fitting has a thermoplastic elastomer (TPE) port cap that can be modified to simulate an individual's ventilation process in the diseased state. The steps to create this modification are listed in this section, while the use of this modified TPE port cap is described in the application section.

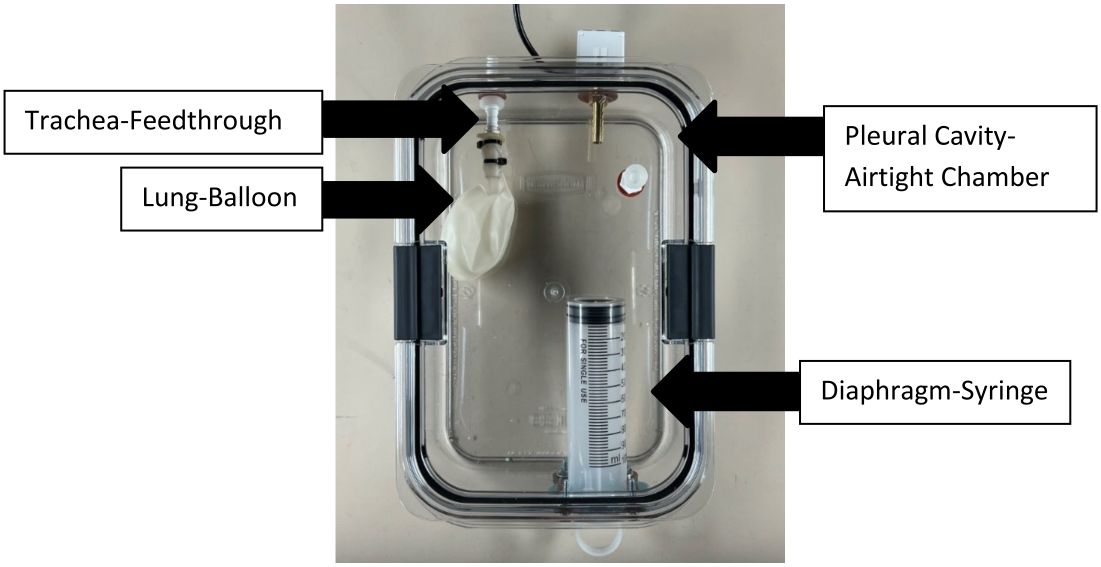

Figure 7: Listed Components of Model

To modify the TPE port cap, a 50-Watt Epilog Helix Laser (24"x18"), shown in Figure 8 was used to cut a hole of 0.5 mm in the center of the cap. The following settings in Table 1 were used for the laser, and the results are shown in Figure 9.

Figure 8: Epilog Helix Laser

Table 1: Laser Printer Settings

Resolution	600 DPI
Job Type	Vector
Horizontal Piece Size (in.)	0.5
Vertical Piece Size (in.)	0.5
Raster Speed	50%
Raster Power	50%
Engrave Direction	Top-Down
Image Dithering	Standard
Vector Speed	1%
Vector Power	100%
Vector Frequency	100 Hz
Engraving	Center-Engraving (Center-Center)
Vector Sorting	Optimize

Figure 9: Laser cut TPE Cap

For the syringe to function as a part of the pleural cavity and increase the volume within the cavity, it is necessary to cut a circular hole to allow air to flow into the syringe as the plunger is moved. The hole cut at the top of the syringe is slightly smaller in diameter than that of the syringe, allowing the plunger to stay inside of the syringe. The syringe with the hole cut in the top is shown in Figure 10.

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Figure 10: Syringe with Hole Cut
Courtesy of Mr. David Yale

A key idea in educating students is for them to be able to understand the differences in the ventilation process when the individual is in a healthy state versus the diseased state. To do this, the Nalgene polypropylene barbed bulkhead fitting that is normally placed through the front lid and covered by an unmodified TPE port cap, is removed to simulate a puncture of the pleural cavity. The laser cut TPE port cap can also simulate the restriction of the airway.

An important part of the design process of this model was creating a leak-proof system. To incorporate the syringe, it was necessary to drill holes into the container for both barbed bulkhead fittings, the syringe, and the compound pressure gauge. To drill the holes for the syringe and its mounting screws, barbed bulkhead fitting and brass fitting for the compound pressure gauge, a Sears/Craftsman 17" Drill Press was used as shown in Figure 11. The drill bits used for each hole are listed in Table 2.

Figure 11: Drill Press Setup

Table 2: Drill Bit Sizes

	Drill Bit Size (Inches)
Barbed Bulkhead Fitting	23/54
Syringe	1 ½
Brass Feedthrough	25/64
Mounting Screws	11/64

Drilling these holes opens up the opportunity for air to leak out of the box. The barbed bulkhead fittings purchased came with silicone gaskets to prevent leaks, as shown in Figure 12. To counteract the possible syringe and compound pressure gauge opening leaks, 1/16th inch-thick red rubber sheet packing was used to create gasket seals for the syringe and the compound pressure gauge. AutoCAD was used to draw the gasket pattern and the rubber sheet was cut with a laser engraving system. To create the gasket seal for the syringe and the compound pressure gauge feedthrough, the laser settings in Table 3 were used. The CAD files of the seals are shown in Figures 13 and 14.

Figure 12: Barbed Bulkhead Fitting with Silicone Gasket

Table 3: 50-Watt Epilog Helix Laser (24”x18”) Settings

Resolution	600 DPI
Job Type	Vector
Horizontal Piece Size (in.)	2
Vertical Piece Size (in.)	2
Raster Speed	50%
Raster Power	50%
Engrave Direction	Top-Down
Image Dithering	Standard
Vector Speed	20%
Vector Power	100%
Vector Frequency	100 Hz
Engraving	Center-Engraving (Center-Center)
Vector Sorting	Optimize

To provide a clean cut, the machine was operated three times in a row. In addition, Play-Doh puddy was added outside of the syringe to ensure a leak proof seal. To fasten the syringe to the box, #8-32x 3/4-inch screws and 5 mm flat washers were inserted through the chamber from the outside. On the inside, SAE #8 washers and nuts were used to secure the screw tightly. Images of the syringe gasket seal and compound pressure gauge used in the model are shown in Figure 15.

Figure 13: CAD File- Syringe Gasket Seal

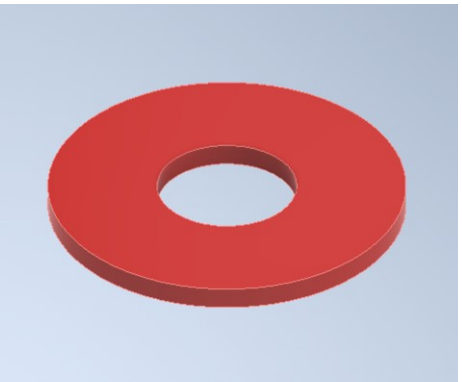


Figure 14: CAD File-Compound Pressure Gauge Seal

Figure 15: Actual Syringe Gasket and Compound Pressure Gauge Seal

The Electronic Components

A compound pressure gauge is a device that can display both positive and negative pressures. In this application, the compound pressure gauge selected was the Autonics PSQ-C01CU-RC1/8, pneumatic type. The listed specifications for the PSQ series included a rated pressure range between -100 and +100 kPa, a 12-24VDC power supply (with a peak-to-peak ripple max of 10%) and a maximum 50 mA current consumption. In this application, the desired output was an analog voltage between 1 and 5 VDC. Operating as a piston type pressure gauge, this means that at -100 kPa the pressure gauge outputs 1 VDC, and at +100 kPa the pressure gauge outputs 5VDC. Based on the outputs that correspond with the lower and upper levels of this range, it can be concluded at 0 kPa the pressure gauge will produce an output of 3 VDC. To allow this compound pressure gauge to measure the “interpleural pressure,” it was necessary to drill a hole into the box and connect a ¼” Hose ID to 1/8” Male BSP Straight Brass Fitting to the pressure gauge. No modifications to the settings of the compound pressure gauge were made, other than prior to each use the gauge was zeroed out by holding the grey up and down arrows simultaneously for 2-3 seconds. The input/output circuit and connections of the PSQ-C01CU-RC1/8 is shown in Figure 16.

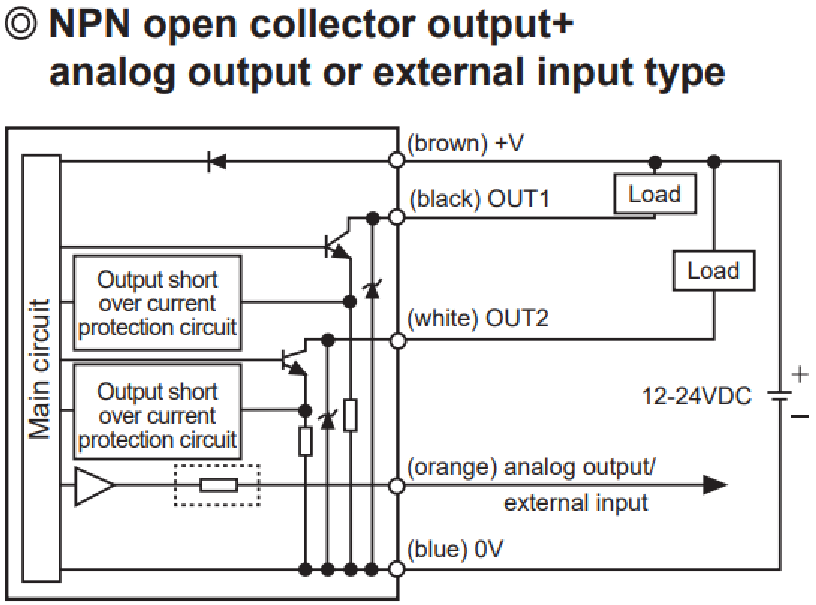


Figure 16: PSQ-C01CU-RC1/8 Output Circuit

For the compound pressure gauge to operate, it must be connected to a 12-24VDC power supply, according to the specification sheet. The brown wire extending from the compound pressure gauge is connect to the positive wire of the power supply. The blue wire extending from the compound pressure gauge is connected to the ground wire of the power supply. The power supply selected in this application is a Jameco 6 Watt AC-to-DC Regulated Linear Wall Adapter. This power supply is within the 12-24VDC range and operates with a peak-to-peak ripple voltage maximum of 50 mV, well under the 10% requirement specified for the compound pressure gauge. When delivered, the output connector of the power supply is a cylindrical female, shown in Figure 17. For it to be of use in the project, it was necessary to remove this output and separate the positive and ground wires to connect them to the output wires of the pressure gauge. After the separation of the positive and ground wires, the ends of the wires were stripped to create a metal-to-metal connection that would allow current to flow.

Figure 17: AC-to-DC Regulated Linear Wall Adapter with Cylindrical Female Output

To provide the student with a visual display of the pressure changes, an ETEPON Digital Oscilloscope Kit with BNC Clips was used. The oscilloscope was chosen because it was within the budget distributed by the SERC grant and it had one channel to measure the pleural cavity It also meets the requirements of creating a robust system because it is a handheld oscilloscope that is easily moveable and not nearly as large or expensive as a lab oscilloscope. For this application, the following settings were used on the oscilloscope to provide visible waveforms:

Table 4: ETEPON Digital Oscilloscope Settings

Voltage Scale	10 mV/div
Time Scale	0.5 s/div
TRIGGER	AUTO
MODE	AC

For the oscilloscope to display the pressure changes in real-time as the model is manipulated through rib cage and diaphragm movement, it is necessary to shift the horizontal position. To do this, it is necessary to press the DIV/SEC button twice and rotate the ADJ knob counterclockwise until the zone shifts as far right possible. To shift the horizontal position, it requires many complete rotations.

The final connection is made between the oscilloscope and the compound pressure gauge to display the intrapleural pressure changes. To do this, the analog output produced in the orange wire is connected to the positive lead of the oscilloscope probe. The ground of the oscilloscope probe is then connected to the blue ground wire of the compound pressure gauge to create a common ground. A comprehensive list of the model's components with part numbers, vendors and prices is listed in Appendix A.

The Shortcomings

There are some shortcomings to the model, which is to be expected since there is no perfect model. In reality, the pleural space is filled with a small volume of fluid and not an air-filled cavity. Like the model in the published paper the project is based on, the presence of an air-filled pleural space instead of a fluid-filled pleural space blunts the effect of the diaphragm and the rib cage movements on the lung volume (1). In addition to budget limitations, this made it difficult to incorporate a second pressure gauge to measure the alveolar pressure, because the small pressure changes in the balloon were not large enough to produce a visible waveform on the graphical display. In the human ventilation system, the interpleural pressure is sub atmospheric in normal conditions. Atmospheric pressure is typically written as 0 cm H_2O, therefore when the lung is at rest the intrapleural pressure will be within a range of -3 to -5 cm H_2O to keep the lunges inflated at rest. In the physical model, the interpleural pressure at rest is 0 cm H_2O. These shortcomings must be identified and explained to students in addition to familiarizing the students with the device prior to they use it in the classroom.

THE HUMAN VENTILATION MODEL VIDEO

The viewing of the supplementary video provided to the students is advised to be completed prior to the use of the model in the classroom. In the flipped classroom, this learning supplement addresses the auditory and visual forms of learning. Lecture material assigned to students provides the reading form of learning, and in turn students have been given three of the four different forms of learning according to the VARK model.

In the beginning of the video, the differences between ventilation and respiration will be described; ventilation is the process by which we move air into and out of our lungs, while respiration is the process of exchanging carbon dioxide for oxygen in the lungs. This model represents the former of the two. The video will then describe the two governing laws of the ventilation process, fluid flow along a pressure gradient and Boyle's Law.

After discussing the governing ideas, the breathing process will be explained conceptually. In the case in which the pressure within the alveoli is lower than atmospheric pressure, the human will inhale. In the case of the pressure in the alveoli being higher than the atmospheric pressure, the human will exhale. In turn, the interpleural pressure will change due to the changes in the lung volume. To understand how these correlate, it will be discussed how the pleura is made of two layers: a parietal layer that lines the inside of the thorax and a visceral layer that covers the lungs and adjoining structures such as blood vessels, bronchi, and nerves. In between these visceral and parietal layers is a small, fluid-filled spaced that is referred to as the pleural cavity. The fluid in the pleural cavity acts like glue, adhering the thorax to the lungs. Therefore, as the thorax expands vertically and laterally, the parietal layer drags the visceral layer along with it, causing the lungs to expand. After the lungs have expanded an adequate amount, the pressure decreases in the alveoli and once the alveolar pressure drops below atmospheric pressure, and air rushes into the lungs.

How the model simulates these ideas is important in understanding its purpose. To demonstrate the two phenomena that were previously discussed, the model components will be discussed. The airtight chamber represents the pleural cavity, the balloon represents the lung, the feedthrough represents the lungs and trachea, and the syringe with the plunger represents the diaphragm. The compound pressure gauge is used to measure the positive and negative pressures relative to atmospheric pressure in the pleural cavity. In the ventilation model, as the syringe plunger moves downward, the volume of the chamber representing the pleural cavity increases, and the pressure within decreases. Therefore, because the pressure in the balloon is greater than the pressure in the chamber, the balloon will inflate. Likewise, the balloon deflates when the pressure within the balloon is less than that of the cavity. The same ideas can be demonstrated through rib cage movement. The use of the model will be displayed simultaneously with the oscilloscope waveform of the interpleural pressure. Lastly, the differences between the model and human ventilation are discussed, including the lack of fluid in the pleural cavity as well as the interpleural pressure at rest.

LAB RESULTS

The model was tested in the lab to ensure proper behavior of the power supply and compound pressure gauge, as well as to provide baseline results of how the model should behave in the healthy state and the diseased state.

For primary testing, a lab oscilloscope was used to provide the baseline for behavior before moving to the more compact handheld oscilloscope. The oscilloscope used is a Rode &

Schwarz RTE 1054, 500 MHz, 5GSa/s Oscilloscope (ID:1317.2500k54-101236-pu). The settings at which the oscilloscope operated at are listed in Table 5.

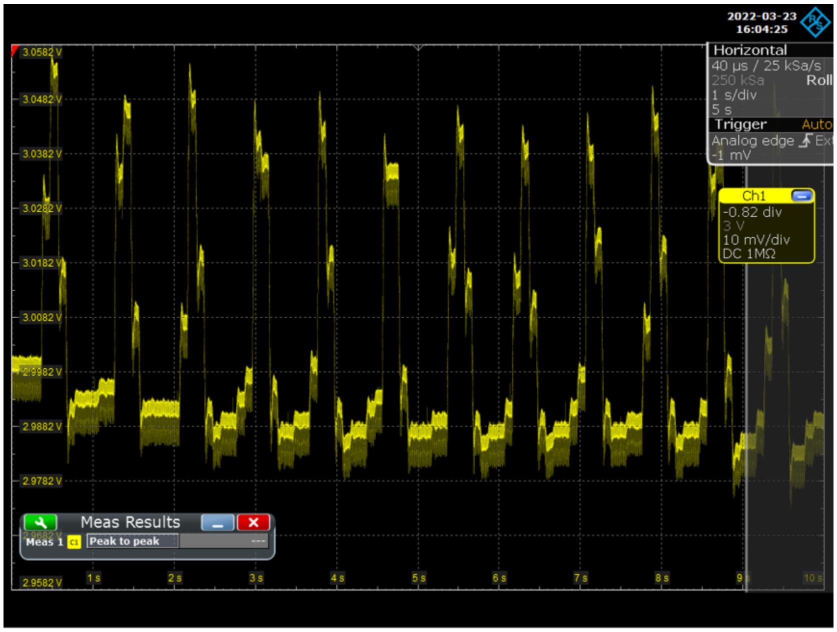
Table 5: Oscilloscope Settings

Coupling	DC 1 MΩ
Acquisition	High Resolution
Resolution	40 us
Acquisition Time	10 s
Time Scale	1 s/div
Horizontal Position	5 s
Trigger	External
Vertical Position	-0.82 div
DC Offset	3 V
Voltage Scale	10 mV/div
Sample Rate	25 kSa/s

In the section discussing the electronic components, it mentioned that at -100 kPa the gauge outputs 1 VDC, and at +100 kPa the gauge outputs 5 VDC. Based on the range described, at 0 kPa the gauge should output the median of the 1-5VDC range, namely 3 VDC. On the oscilloscope, the oscilloscope settings require that the DC offset be set to 3 VDC to view a visible waveform. This range implies that for every 2 VDC, the pressure changes 100 kPa. For every 1 mVDC, the pressure changes 0.05 kPa. At rest, the compound pressure gauge is at 0 kPa and the oscilloscope will show a visible flat line at approximately 3 VDC. When the diaphragm and rib cage are manipulated to simulate inhalation and exhalation, the waveform will move up or down relative to 3 VDC, showing the change in pressure in the cavity relative to the atmospheric pressure at 0 kPa. The following results confirm that the compound pressure gauge is displaying the expected behavior.

In each portion of testing, rib cage movement is simulated by squeezing the box and diaphragm movement is simulated by pulling the syringe in and out. The first portion of lab testing focuses on change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual that is in the healthy state.

Figure 18: Interpleural Pressure in the Healthy State: Rib Cage Movement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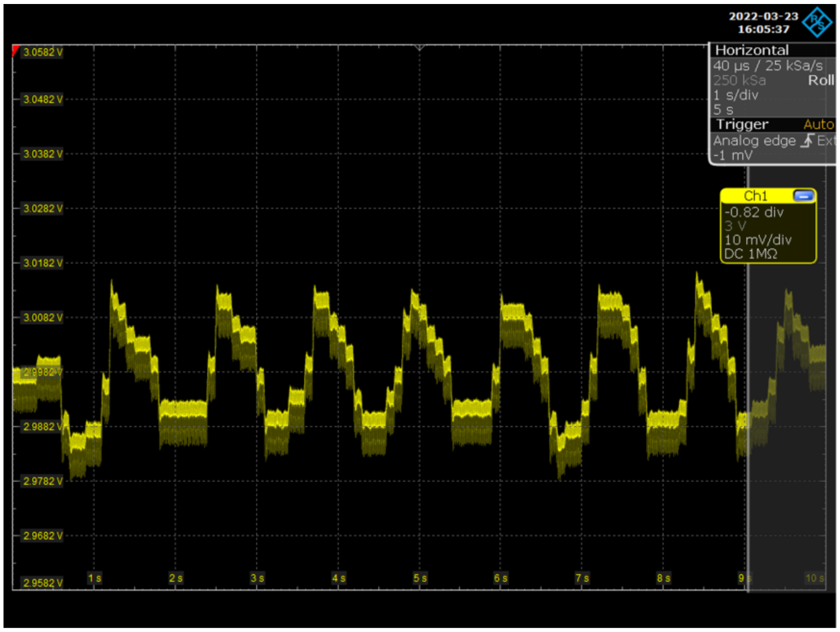
Horizontal
40 µs / 25 kSa/s
250 kSa Roll
1 s/div
5 s

Trigger Auto
Analog edge Ext
-1 mV

Ch1
-0.82 div
3 V
10 mV/div
DC 1MΩ

Meas Results
Meas 1 C1 Peak to peak ---

Figure 19: Interpleural Pressure in the Healthy State: Diaphragm Movement



The second portion of lab testing focuses on change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual that is in the diseased state, suffering from tachypnea. In this state, a human has abnormally rapid, shallow breathing. In this scenario, to simulate a higher respiration rate, the box is squeezed more rapidly.

Figure 20: Interpleural Pressure during Tachypnea: Rib Cage Movement

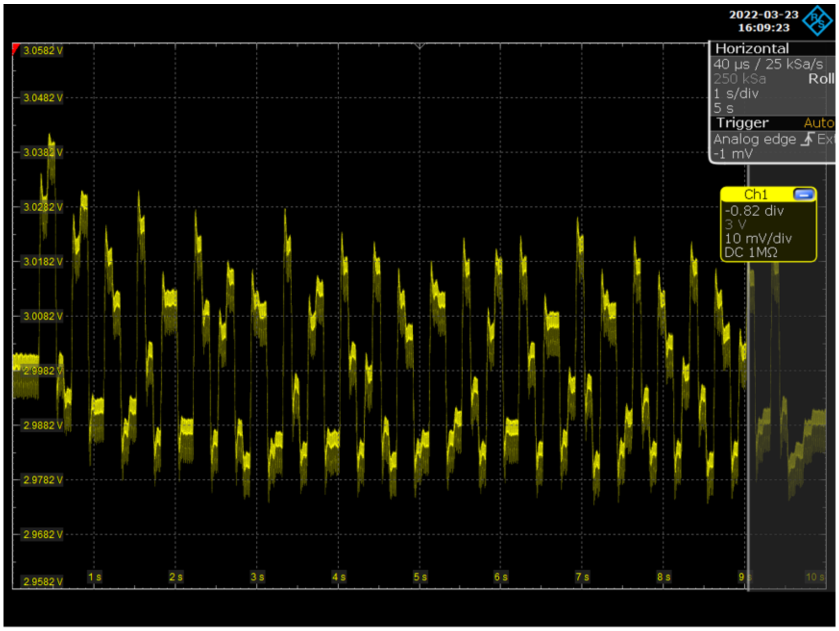
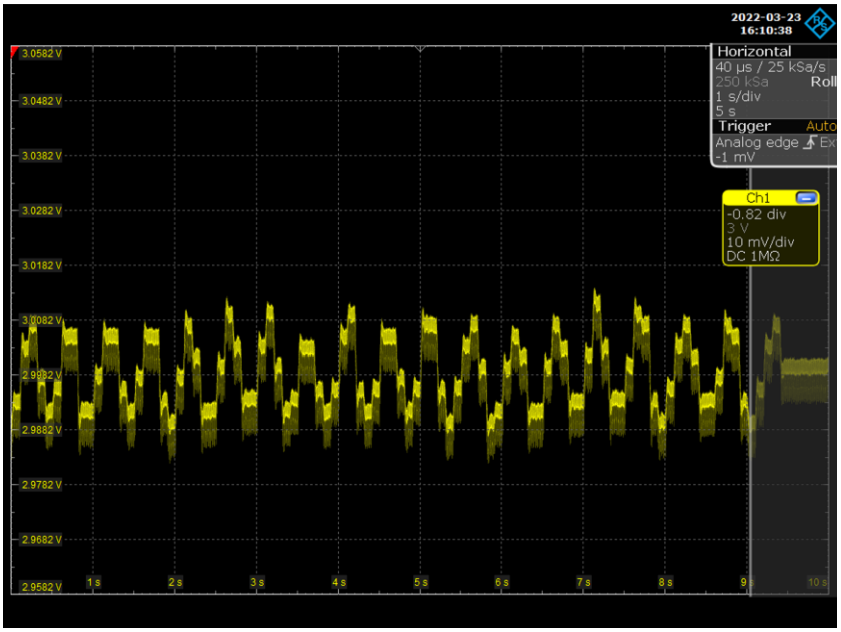


Figure 21: Interpleural Pressure during Tachypnea: Diaphragm Movement


2022-03-23
16:10:38
Horizontal
40 µs / 25 kSa/s
250 kSa Roll
1 s/div
5 s
Trigger Auto
Analog edge Ext
-1 mV
Ch1
-0.82 div
3 V
10 mV/div
DC 1MΩ

The final portion of lab testing focuses on the change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual with dyspnea, also known as labored breathing.

Figure 22: Interpleural Pressure during Dyspnea: Rib Cage Movement

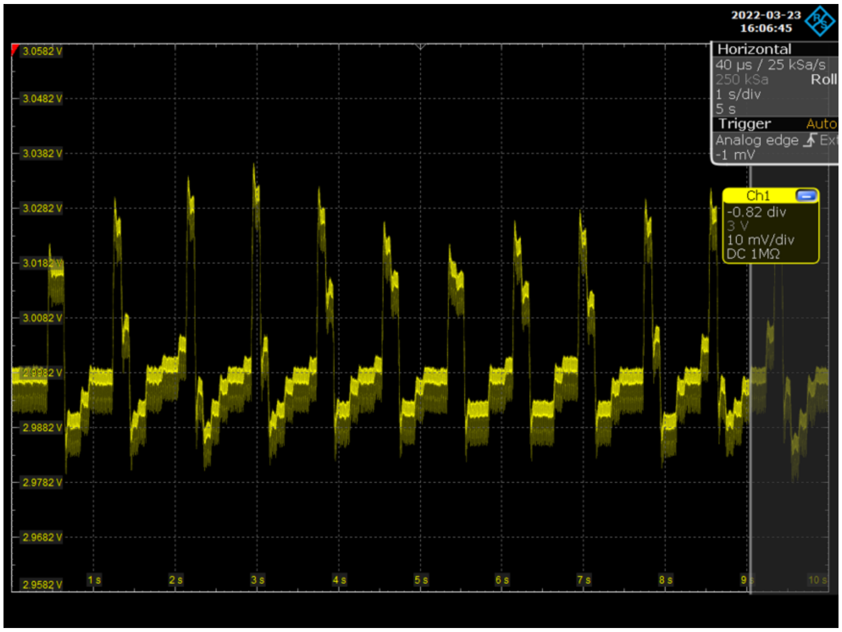
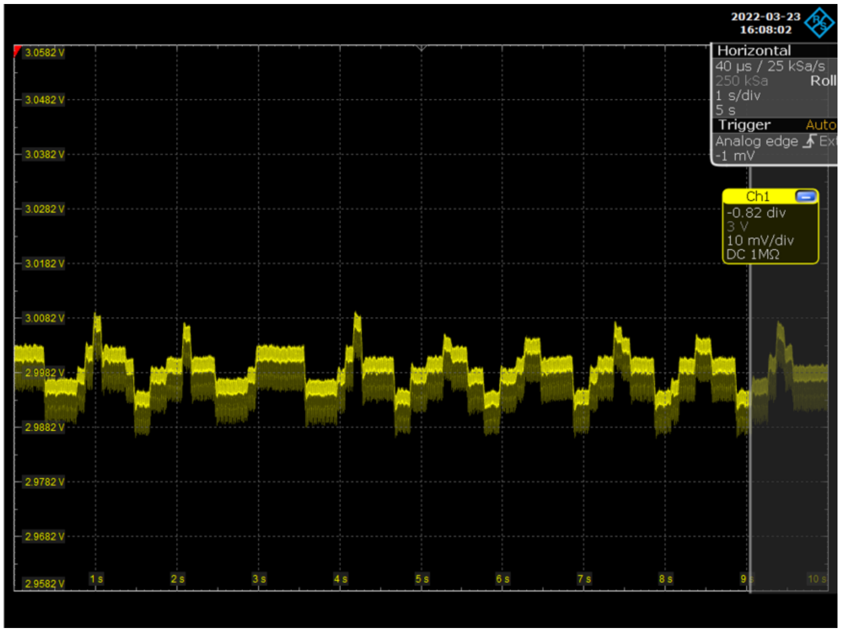

2022-03-23
16:06:45
Horizontal
40 µs / 25 kSa/s
250 kSa Roll
1 s/div
5 s
Trigger Auto
Analog edge Ext
-1 mV
Ch1
-0.82 div
3 V
10 mV/div
DC 1MΩ

Figure 23: Interpleural Pressure during Dyspnea: Diaphragm Movement



A comparison of the voltage changes and corresponding pressure changes is shown in Table 6. It can be concluded that the rib cage produces more significant pressure changes within the pleural cavity than the diaphragm does in both the healthy state and the diseased states. This however is not the case in actual human ventilation, and is therefore a limitation of the model.

Table 6: Pressure Changes in the Pleural Cavity

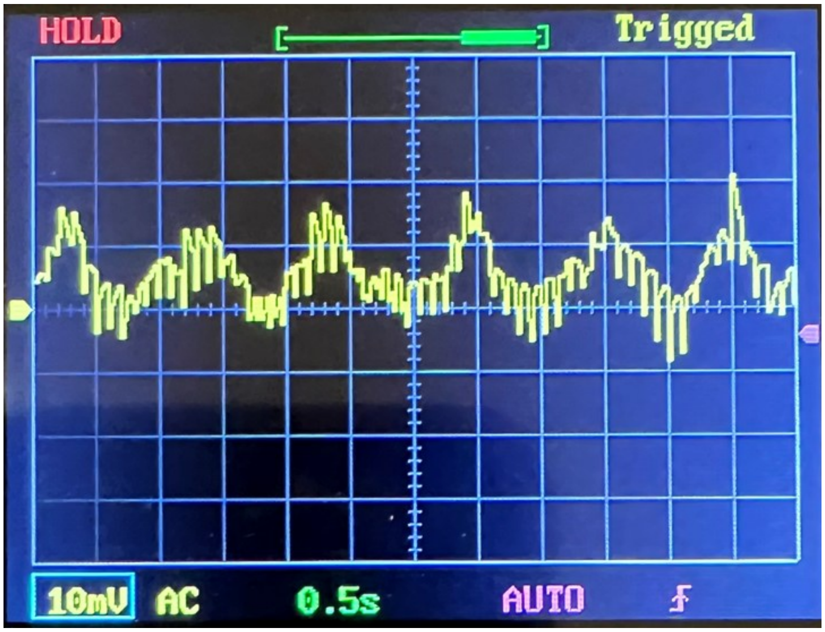
State	Average Peak to Peak Voltage (mV)	Corresponding Pressure Change (kPa)
Healthy- Rib Cage Movement	99.895	4.99
Healthy- Diaphragm Movement	42.138	2.11
Tachypnea- Rib Cage Movement	58.875	2.94
Tachypnea-Diaphragm Movement	31.872	1.59
Dyspnea- Rib Cage Movement	54.566	2.73
Dyspnea-Diaphragm Movement	21.525	1.08

After determining the oscilloscope that would be used in the actual Pulmonary Module, further testing was done to confirm that the oscilloscope displayed results like the oscilloscope used during primary testing. The oscilloscope undergoing testing and intended for use in the module is an ETEPON Handheld Oscilloscope.

The first portion of lab testing focuses on change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual that is in the healthy state.

Figure 24: Interpleural Pressure in the Healthy State- Rib Cage Movement

Figure 25: Interpleural Pressure in the Healthy State- Diaphragm Movement



The second portion of lab testing focuses on change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual that is in the diseased state, suffering from tachypnea.

Figure 26: Interpleural Pressure during Tachypnea- Rib Cage Movement

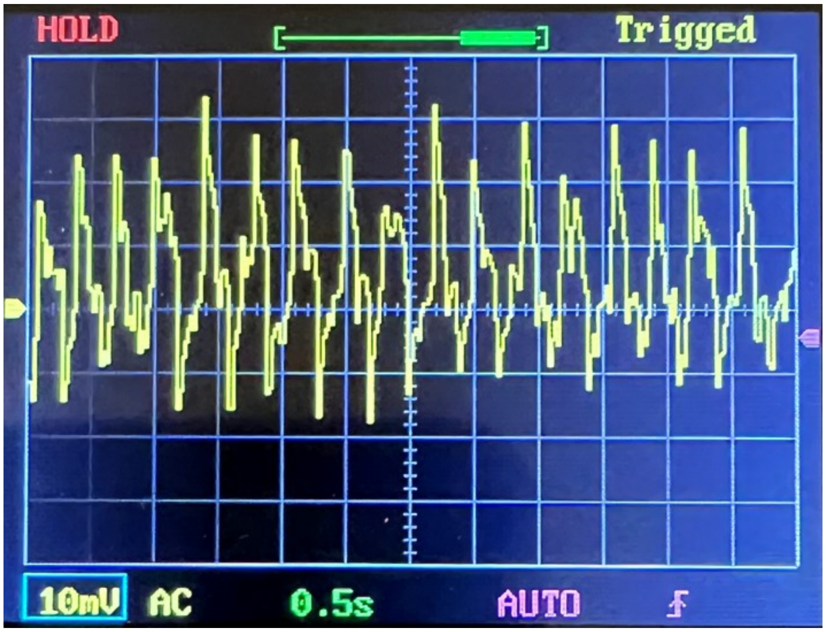
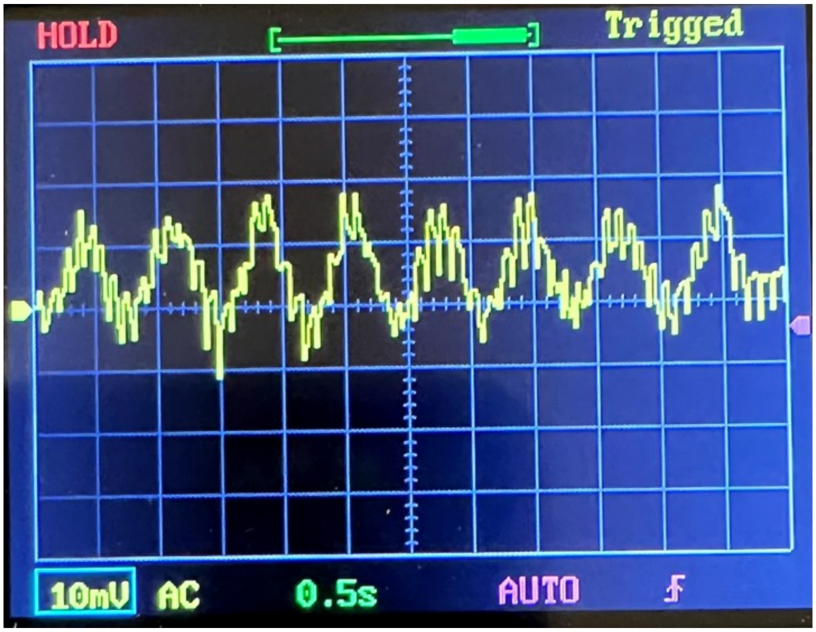


Figure 27: Interpleural Pressure during Tachypnea- Diaphragm Movement



The final portion of lab testing focuses on change in interpleural pressure caused by rib cage movement and diaphragm movement in an individual that is in the diseased state, suffering from dyspnea.

Figure 28: Interpleural Pressure during Dyspnea- Rib Cage Movement

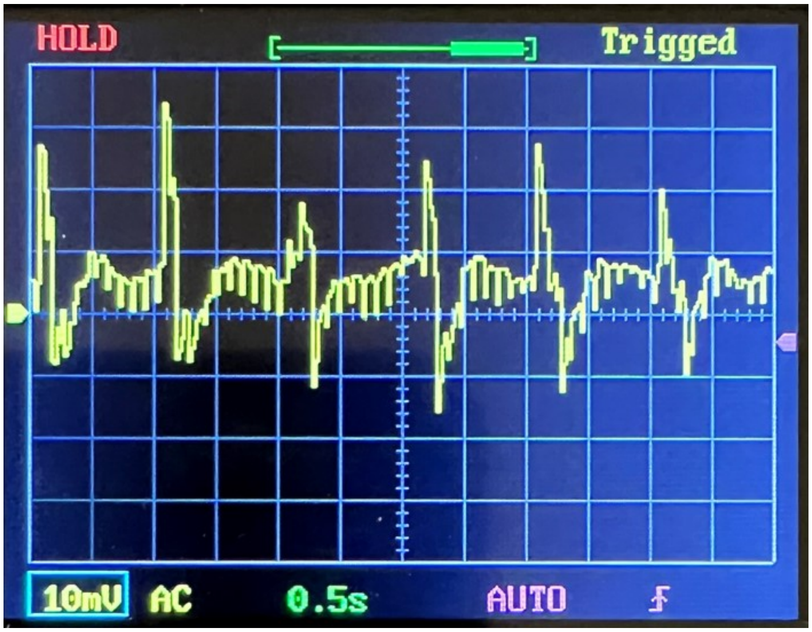
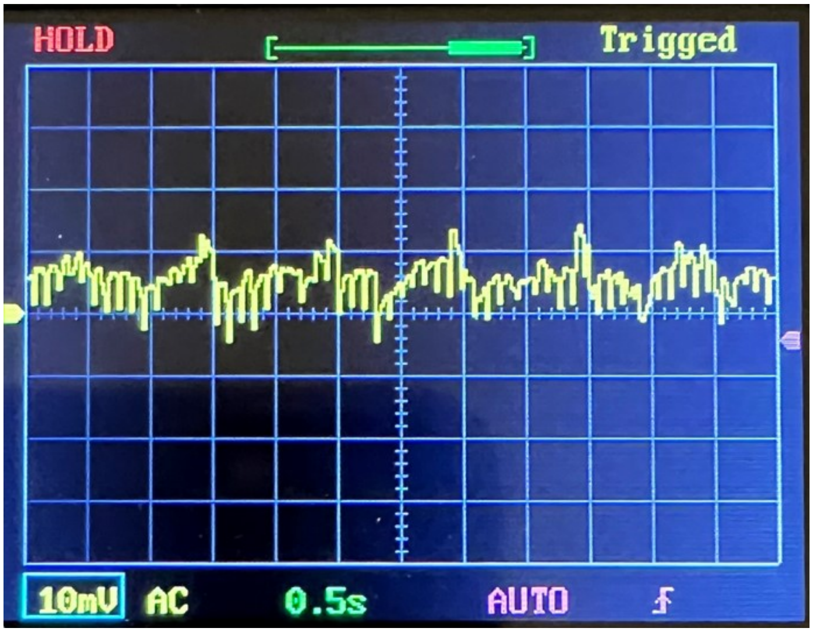


Figure 29: Interpleural Pressure during Dyspnea- Diaphragm Movement



APPLICATION

There are several applications of this model: understanding the human ventilation process in a healthy individual, understanding the human ventilation process in an individual suffering from tachypnea, and understanding the human ventilation process in an individual suffering from dyspnea. This section will discuss how the model is manipulated to simulate these three different scenarios and the exercises that will be provided to students to challenge them to think critically.

The primary focus of the model is for students to gain a better understanding of how the pressures change during the human ventilation process. To understand the magnitude of a diseased state on the ventilation process, it first must be understood how the pressures change in a human in the healthy state during the ventilation process. The model simulated in a healthy state is shown in Figure 30.

Figure 30: Healthy State Model

In this state, the barbed bulkhead fitting representing the trachea does not have the modified, laser cut TPE port cap covering it. The barbed bulkhead fitting on the front of the model is covered by the TPE port cap to ensure there is no opening for air to enter the pleural cavity. This models the ideal scenario, the healthiest state in which an individual can be. It models quiet breathing, which is an unconscious action controlled by the brainstem.

After the baseline model behavior has been established for ventilation when the human is in a healthy state, it is possible for the model to be modified to display ventilation when the human is in the diseased state. The first diseased state that will be observed is tachypnea. Tachypnea is a condition that refers to abnormally rapid breathing. The normal breathing rate for an adult is 12 to 20 breaths per minute, however in tachypnea it is more than 20 breaths per minute. To understand tachypnea, it is important to understand the physical mechanisms that give rise to the condition. The idea is based on Poiseuille’s law, which states that small changes in the radius of the bronchi and bronchioles results in a large changes in resistance [6]. In general, turbulent air flow tends to occur in airways with larger diameters and at increasing flow velocities. With forced inspiration and expiration, turbulent air flow occurs in restricted airways at smaller diameters. This turbulence leads to an increase in the energy require for flow to occur and increases the work of breathing. This is what happens in the bronchi and bronchioles located in the lungs, which are the cylindrical tube-like structures that air flows through as we breath in and out.

The model can be manipulated to simulate this condition simply by placing the modified TPE port cap over the barbed bulkhead fitting that represents the trachea, as shown in Figure 31. The diameter of the hole in the TPE port cap is smaller than that of the opening of the barbed bulkhead fitting. This causes more resistance to the air flow in the lung through the trachea as inspiration and exhalation occur and shows Poiseuille’s Law in action.

Figure 31: Model Simulating Tachypnea

This module challenges students to understand the fundamentals of the system that they are studying, but it also challenges them to think critically about the conditions that can arise and how to treat those conditions. The following questions will be asked of students during the module:

1. Describe the physical mechanisms giving rise to pulmonary hyperinflation.
2. What tests would you use to diagnose pulmonary hyperinflation?
3. How would you treat pulmonary hyperinflation?

The second diseased state that can be modeled is dyspnea. Dyspnea is shortness of breath and can often be described as an intense tightening in the chest, air hunger, difficult breathing, breathlessness, or a feeling of suffocation [7]. One mechanism that can give rise to dyspnea is an open chest wound, also known as a sucking chest wound, leading to a pneumothorax. Figure 32 displays an open chest wound. In this condition, a large amount of air rushes into the pleural cavity and in turn forces the lung to collapse into a smaller volume. Symptoms of an open chest wound include sudden chest pain, shortness of breath, and rapid breathing [8].

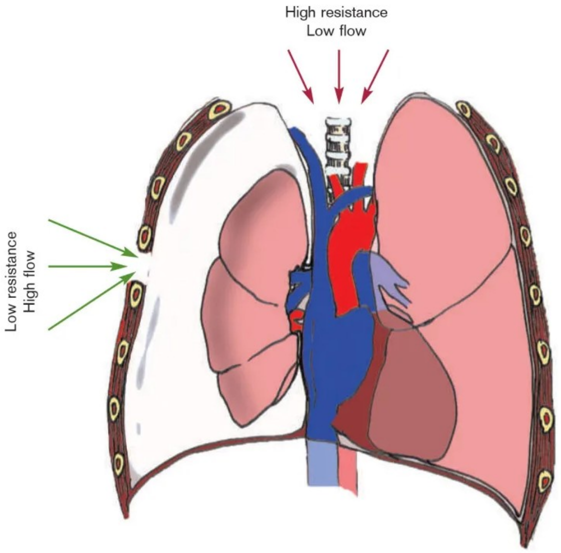


Figure 32: Open Chest Wound

These symptoms all correlate to the condition of dyspnea and can easily be simulated by removing the TPE port cap covering the barbed bulkhead fitting on the front of the model, as shown in Figure 33. The removal of this cap allows air to rush into the pleural cavity, simulating the open chest wound. In turn, the effects of dyspnea on the pressures during ventilation can be observed and compared to ventilation in a healthy human.

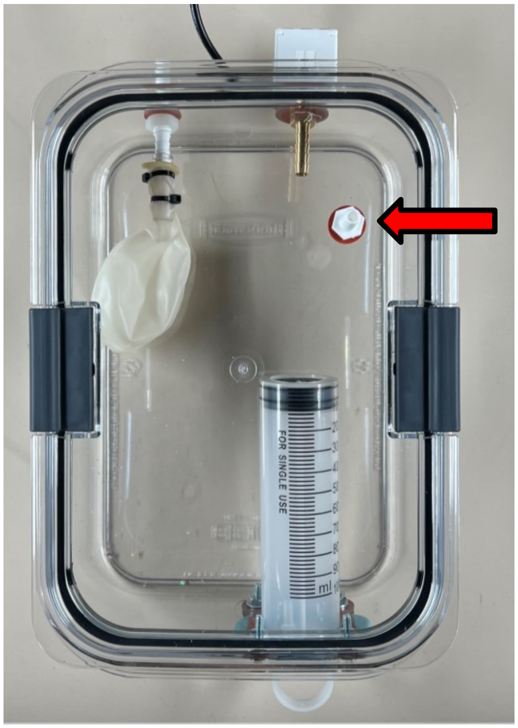


Figure 33: Model Simulating Dyspnea

In this scenario, students will also be provided a set of questions that will gauge their understanding of the fundamentals of the system and challenge their critical thinking skills. These questions will be listed as follows:

1. Explain the physical mechanism giving rise to dyspnea and chest pain resulting from a pneumothorax.
2. What tests would you use to differentiate a pneumothorax from a pulmonary embolism? Describe the expected findings from each test for each disease?

3. How would you treat a pneumothorax?

4. Contrast the mechanisms giving rise to respiratory-induced dyspnea versus cardiovascular-induced dyspnea.

EDUCATIONAL TESTING

Understanding that people learn differently is only one part of ensuring that students succeed. Understanding that every educational experience is as valuable as another is the other part of that success. Flipped classrooms are being implemented around the country, especially in medical schools, including the TCU School of Medicine. This allows students, as previously mentioned, to learn the fundamentals outside of class and focus on analyzing, synthesizing, and evaluating in class. With the use of this model and the corresponding video in addition to lecture materials/reading assigned, students can have a comprehensive educational experience. It is also important to analyze how successful this tool is in aiding their understanding of the laws that govern the ventilation process, their retention of material, and how effective it is in providing a good representation. The core idea behind the experiment that this paper is based on was providing pre and post surveys to identify if the model increased their understanding and confidence in the ventilation process. A similar process could be done with the TCU School of Medicine students during the Pulmonary Module. This survey would include content questions that gauge their understanding of the ventilation process and the physical mechanisms associated with two diseased states. To administer the survey, approval by the Institutional Research Board at TCU would be required, as the project involves human research subjects. This form of surveying would fall under the category of exempt human subjects research because it involves the collection of anonymous data and poses the least potential threat to the well-being of the research subjects. The following is the 10-question survey that would be administered to students prior to their use of the model and after their use of the model. Questions 1 and 2 are not to be included in the statistical analysis of results.

Pre-survey and Post-survey Questions

1. How well do you understand ventilation pressure changes in the healthy state?
    1. Poor
    2. Fair
    3. Good
    4. Very Good
    5. Excellent
2. How well do you understand the impact of a diseased state on ventilation pressure changes?
    1. Poor
    2. Fair
    3. Good
    4. Very Good
    5. Excellent
3. During inhalation, the interpleural pressure is:
    a. positive and negative
    b. positive and zero
    *c. negative and zero**
    d. only negative
    e. only positive
4. During exhalation, the interpleural pressure is:
    a. positive and negative
    *b. positive and zero**
    c. negative and zero
    d. only negative
    e. only positive
5. When the chest is punctured, which of the following occurs?
    *a. the lungs collapse**
    b. the lungs inflate
    c. the lungs return to functional capacity
6. The respiration rate ______ and the pressure changes in the pleural cavity are _______ during tachypnea when compared to the healthy state.
    a. increases; larger
    b. decreases; the same
    *c. increases; smaller**
    d. decreases; larger
    e. decreases; smaller
7. The respiration rate ______ and the pressure changes in the pleural cavity are _______ during dyspnea when compared to the healthy state.
    a. increases; larger
    b. decreases; the same
    c. increases; smaller
    d. decreases; larger
    e. decreases; smaller
8. When the volume of the pleural cavity increases, the pressure in the pleural cavity ______.
    a. increases
    *b. decreases**
    c. stays the same

9. When the diaphragm relaxes, the interpleural pressure ________.

*a. increases**
b. decreases
c. returns to atmospheric pressure

10. During inhalation, the rib cage ______ and the diaphragm ______.

a. contracts; relaxes
b. contracts; contracts
c. expands; expands
*d. expands; contracts**
e. expands; relaxes

An additional study could be performed to identify the impact of the model using the same survey questions, but instead using a control group and an experimental group. The control group would take the pre-survey, receive a traditional lecture in class and then take the post-survey. The experimental group would take the pre-survey, receive a traditional lecture, watch the video demonstration in class and complete the exercises, and then take the post survey. Identical to the study completed at the University of Wisconsin, the pre- and post-survey scores of the control and experimental groups would be compared to identify if the model contributed to student confidence and understanding of the ventilation process. This study would also require approval by the Institutional Research Board at TCU under the same circumstances as previously described.

CONCLUSION

This project focuses on multimodal learning in the framework of medical students at the TCU Medical School in their Case Application Exercises (CAS) in the Pulmonary Module. In a flipped classroom, the supplementary video provides the auditory and visual forms of learning and describes the physical mechanisms of human ventilation. In addition to assigned reading material, the basic content and fundamentals are covered in three of the four forms of learning prior to even entering the classroom. The model is a robust and accurate representation of the system, allowing for a hands-on experience that addresses the last form of learning, kinesthetic learning. Professors can make the most effective use of class time and achieve the higher levels of thinking that includes analysis, synthesis, and evaluation. The model is low-cost and made of readily available materials, allowing for it to be easily replicated and potentially used in DO, PA, and Nursing programs in addition to the MD program in the future.

APPENDIX

Table A: Components for One Model

Component	Vendor	Model No.	Quantity for one model	Price (USD)
Red Rubber Sheet Packing	ACE Hardware	40215	1	5.99
12 VDC Power Supply	Jameco	162996	1	12.95
Barbed Bulkhead Fitting; ¼” (2/package)	Cole-Parmer	06259-10	1	38.00
2.3 L Leak Proof Rubbermaid Container	Target		1	12.99
ETEPON Oscilloscope Kit	Amazon		1	46.99
Compound Pressure Gauge; +/- 100 kPa	Autonics USA	PSQ-CO1CU-Rc1/8	1	176.95
Nuobu Syringe- 1-1/2” Barrel Outer Diameter (5/package)	Amazon		1	9.99
Latex Balloon (Small/Medium)	Party City		1	1.19
Edge Industrial ¼” Hose ID to 1/8” Male BSP Straight Brass Fitting (5/package)	Amazon		1	16.90
Hillman #8-32x3/4 in. Round Combo with Nuts (75 pieces/package)	Lowes	68648	1	5.98
Hillman SAE #8 Flat Washers (100 pieces/package)	Lowes	3834	1	4.98
Play-Doh	Amazon		1	5.25
Hillman 5 mm Flat Washers (20/ package)	Lowes	127073	1	2.28
Hillman 7/16 in. Flat Washers (6/package)	Lowes	490690	1	1.28
			Total Cost:	341.72 USD

**** Note: One singular model requires only one syringe, brass fitting, and 7/16 in. flat washer. One singular model also only includes four #8-32x3/4 in. nuts, SAE #8 flat washers, and 5 mm flat washers. Prices listed for components with multiple pieces per package are the cost of all pieces in the package.

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