**Learning Physiology Made Simple And Fun:**

**A Review of Teaching Resources From The Journal Advances In Physiology Education**

**Vinay Oommen, Praghalathan Kanthakumar, Anand Bhaskar, Silviya Rajakumari Jared, Snekalatha S,**

**Aneesh Joseph, Kamalakannan V**

Department of Physiology, Christian Medical College, Vellore 632002, Tamil Nadu, India

**Abstract:** There are many resources available for Physiologists to help improve the quality of their teaching. This review is a collection of simple and innovative models as well as other teaching resources that can be applied in the Indian setting. Articles from 1989 to 2012 from the journal Advances in Physiology Education were reviewed. A set of five criteria was applied to identify if the idea presented could be replicated easily and at an affordable cost in the Indian setting. The selected articles were reviewed and presented system wise. This collection of resources will serve as an index to help Physiologists locate and implement easily affordable and practical tools to supplement their teaching.

Key Words: Physiology, Learning, Teaching Resources

**Author for correspondence:** Vinay Oommen, Assistant Professor, Department of Physiology, Christian Medical College, Vellore 632002. email: [vinayoommen@cmcvellore.ac.in](mailto:vinayoommen@cmcvellore.ac.in)

**Introduction:** The aim of every teacher in Physiology is to make his or her teaching more effective and interesting. In this effort, illustrations, stories, animations, video clips and various other teaching aids are often used. In addition to original ideas, materials are also sourced from text books, the internet, as well as from research articles. Advances in Physiology Education is a peer reviewed journal of the American Physiological Society dealing with physiology education. It contains a wealth of various Physiology research articles and teaching resources under various sections.

This review analyzes the teaching resources in this journal that can be easily constructed or used in the Indian setting.

**Materials and Methods:** Articles available in all online issues of the Journal Advances in Physiology Education were included. This spanned issues from 1989 to September 2012.

Any article that dealt with innovative methods in teaching, using additional material and resources was initially selected. The innovative material could include novel illustrations, physical models illustrating physiological principles, software, animations as well as laboratory exercises. These articles were then assessed for the fulfillment of the following criteria: The topic addressed should be relevant to the undergraduate M.B.B.S. curriculum in India.

The time frame of presentation of the model must be such that it can be easily integrated into teaching. The cost must be affordable in the Indian setting.

The resource must be easily constructible. In the case of digital resources such as computer programs, animations and analysis software, the software must be available freely on the internet.

The Physiology resources that fulfilled all these criteria were reviewed and collated into a system-wise presentation. The underlying principle governing the selection of these articles was that these models should be easy to construct in the Indian medical college setting. Given below are the articles reviewed in a system wise manner.

**General and molecular Physiology:** Haddad and Baldo have described a model to explain the mechanism of diffusion using coin toss1. In this model the students themselves represented the diffusing particle and the coin toss was used to obtain the direction of one-dimensional random movement. This simple class room experiment elegantly explains the random nature of diffusion and portrays the potential of a random factor to produce an emergent behaviour.

The effect of temperature on the sodium potassium pump was demonstrated as a simple laboratory exercise by Honig *et al*.2. The sodium and potassium levels of blood were analyzed at different temperatures.

Numerous models have been used to describe membrane potential in more understandable terms. A hydrostatic model was described by Sircar *et al*. using U tubes, pressure gauges and stop cocks3. A group activity involving students, each holding different coloured balloons representing different ions was used to illustrate the action potential by Carvalho *et al*.4. Milanick has designed a simple model using blue and red-coloured solutions that represent sodium and potassium ions to describe the principle of membrane potential5. In this model the valves that controlled the solution flow stood for the permeability of the membrane to that particular ion. The change in membrane potential with change in permeability to different ionic species can be explained using this model. In another exercise, Moran *et al*. have used a simple dialysis membrane to demonstrate the generation of membrane potential across the plasma membrane6. The technique illustrated by the authors enabled the student understand the concept of membrane potential. A graphical method of representing electrical and chemical driving forces as separate vector arrows has been described by Nolan to facilitate the understanding of electrochemical driving force across the cell membrane7.

The article by Cardozo described the use of springs to show the effect of ionic conductance on membrane potential. A pointer was kept in position (membrane potential) by connecting two opposing springs representing potassium and sodium conductance. Increasing the sodium conductance by adding more springs on the positive side caused the pointer to move towards the sodium equilibrium potential8.

[Johanna Krontiris-Litowitz](http://advan.physiology.org/search?author1=Johanna+Krontiris-Litowitz&sortspec=date&submit=Submit) has described an activity that used clay and beads to help students build the structure of an ion channel. It also involved construction of a neuronal model and describing the passive properties of the cell membrane9.

Geraldo Gamba has used an analogy of the monthly paycheck, banking as well as personal expenses to illustrate the concepts involved in intermediate metabolism10. Stavrianeas and Silverstein have used the analogy of power generation from fuel and its related processes to explain the process of glycolysis 11.

The ratcheting action of molecular motors was illustrated by DoHariis *et al.* using commonly available household items. This model illustrated how vibrations can be used to cause movement along one particular direction12.

Baptista describes a pictorial analogy of cell culture to teach the students about the concept of homeostasis13. The composition of the fluid around the cultured cells is maintained by the periodic changing of the culture medium. The temperature is also kept constant by keeping the cells in an incubator. The author feels that the concept of cell culture can be used to explain the concept of homeostasis

**Muscle Physiology:** Jittivadhna *et al*. have described a model of sliding filament mechanism of skeletal muscle using plastic pipes, transparent sheets, acrylic plate, balloon sticks and springs14. Apart from explaining the arrangement of thick and thin filaments in a myofibril, this model also gives insight into the mechanism of sliding filaments.

Guiliodori *et al*. have designed a model using a syringe, springs and an aneroid manometer to demonstrate Hooke’s law15. In this model the authors have shown the direct relationship between the spring length and pressure developed within the syringe by coupling these components. This relationship was used to explain the physiological principles such as passive length-tension relation of the muscle, elastic recoil of the lungs and large blood vessels.

An exercise to calculate the amount of ATP that would be used by the muscles of a marathon runner was designed by Buono *et al*. to underscore the importance of generating ATP on an ‘as and when required’ basis through various metabolic pathways16.

Easton has described the use of a tower shaped muscle chamber made from simple plastic beakers to mount the nerve muscle preparation vertically. The tower could be filled with required volume of physiological solution. A cantilever was used to modify the force transducer to monitor length and enable recording of isotonic contractions in a setting which was designed to make isometric recordings17.

The article by Bhaskar *et al*. described the construction of a simple EMG amplifier to record the EMG signals in a computer using the sound card as the data acquisition device. The authors have also provided the link for downloading the free software used for the recording and playback of the recorded EMG signals18.

**Blood and Body Fluids:** A simple exercise to illustrate the concept of osmotic fragility of erythrocytes has been described by Sanjay Kumar19. The exercise used 3 polyethylene bags blown to the maximum, one-half, and one-quarter of their volume and were marked as S (spherocyte), N (normal RBC) and L (Leptocyte) respectively. The author applied mechanical pressure which is analogous to hypotonic stress imposed on the RBC’s which in turn was compared with the surface/volume ratio. The bag filled fully with air (S) burst first as opposed to the N and L which is explained by surface/volume ratio.

**Endocrine Physiology and Metabolism:** An interesting way of teaching thyroid function was described by Lellis-Santos *et al*. The authors used a detective case and different aspects of the thyroid condition were offered as clues to the various groups to help them solve the case20.

The control of glucose levels in the blood has been illustrated by David Swain using a beaver and pond analogy21. The beaver maintains a constant water level in the pond for functioning of its lodge which is analogous to the maintenance of the blood glucose level. The beaver controls the water level in the pond by regulating the outflow from the pond which is analogous to the glucose moving from blood to the tissues (regulated by insulin) and inflow of water into the pond through the stream is analogous to the glucose entering the stream through absorption from gastrointestinal tract or release of glucose from the liver (regulated by glucagon and counter-regulatory hormones).

Passos *et al*.explained metabolism using students as volunteers. Two sets of students were used. One set received a hyperglycemic meal, while the other received a hyperlipemic meal. Blood parameters such as glucose and triglycerides were measured at different points in the day and plotted to explain different aspects of metabolism 22.

**Reproductive system:** Satheesha Nayak has described an interesting way to teach the anatomical relations of the female reproductive systems23. Three student volunteers represented the uterus, the bladder and the rectum while a blanket over them represented the various peritoneal folds.

**Cardiovascular Physiology:** A water tower analogy to illustrate the cardiovascular function and its control has been described by David Swain. In this analogy the author has compared the water pump to the heart, the water tower to the aorta, the parallel pipelines to the arteries and the faucets to the arterioles 24. A simple method to demonstrate various phases of cardiac cycle using commonly available materials like plastic bottles and valves has been described by RD Russ25. Rodenbaugh *et al*. have developed a cardiovascular model using inexpensive materials such as syringes, tubing and balloons26.

A group activity to demonstrate the cardiac cycle has been described by Carvalho *et al*. The cardiac cells were represented by the students themselves. The students held the hands of each other to simulate the whole heart. The group activity was used to illustrate the cardiac cycle4.

Giuliodori *et al*. have described a method to construct simple valves using tubings and balloons27. This simple set up can be used to explain the functioning of valves in the veins.

An experiment to demonstrate the effects of the autonomic nervous system on the heart rate was performed using atropine and the students as subjects28. The effects of subcutaneous atropine were documented in this laboratory exercise. This aided the discussion on autonomic function.

Collin *et al*. devised laboratory exercises to illustrate the various cardiovascular changes in diabetic individuals29. Students were provided with data in the form of figures and tables which dealt with cardiovascular parameters in normal and diabetic individuals. They were asked to analyze the information and answer a list of questions.

Pressley *et al*. have described an educational activity called “Healthy Heart Race”, where students were asked to pump fluid using a hand pump through a tubing30. In this activity the students competed against each other. In some cases the tubing was pinched to illustrate a partial block of the vessel. The authors recommended this activity for science fairs and other student programs.

Belusic and Zupancic have constructed a finger pulse sensor using the piezoelectric device found in a singing greeting card31. The sensor recorded the finger pulse by sensing the volume change that is produced by each pulse wave. The voltage change produced by the deformation of the piezoelectric sensor was acquired by a data acquisition system to generate the pulse wave.

A set of experiments using materials like a tub of water, snorkels and towels to illustrate the changes in heart rate that can occur during the diving reflex and as a result of apnea have been described by Hiebert and Burch32. Pontiga and Gaytán have used an experimental approach to explain basic concepts in hemodynamics33. A mechanical model was constructed using a pressure transducer, tubing and flow meters attached to a data acquisition system. This set up was used to study Poiseuille’s equation, the effect of narrowing of vessels and also vascular networks.

A simple method of demonstrating the origin of ECG waves has been described by Bhaskar and Vinod. The ECG was recorded from a frog heart using three bipolar limb leads and chest lead of a standard human ECG machine. The heart was exposed and the ventricle and atria were removed individually to demonstrate their contribution to the entire ECG waveform34.

**GIT:** David M Lawson has described a model that helps to understand the volume of fluid secreted into and absorbed by different organs of the gastro intestinal tract35. The model was constructed by using plastic bottles, tubing and circulation pumps.

Odenweller *et al*. have developed two sets of card games that facilitate the understanding of gastrointestinal physiology. The games were developed using the rules of existing card games that the students were familiar with36.

The article by LePard described the demonstration of the relationship between intestinal slow waves and muscle contraction by students. One student was asked to sit and stand rhythmically to demonstrate the slow wave oscillation. Another student was asked to stand still to demonstrate the basal tone of the intestine. Whenever the slow waves reach the threshold for action potential as during the release of excitatory neurotransmitter, the person representing slow wave stands on the toe to represent the spike potential. At the same time, the person representing muscle contraction squats to demonstrate the shortening of the muscle during contraction. They also used this demonstration to show the effect of nor-epinephrine on slow waves and contraction37.

The article by Abdulkader *et al*. described an experiment to demonstrate the effect of sympathetic and parasympathetic stimulation on salivary secretion. The students were asked to collect saliva for 10 minutes before the experiment (control). One group of students collected saliva while chewing gum and the other group collected saliva while performing an aerobic exercise. The salivary flow increased in the chewing gum group and there was a reduction in salivary flow in the exercise group compared to the control38.

**Respiratory Physiology:** There are numerous teaching materials available for the study of the respiratory system. A set of web based lecture notes in physiology and pathophysiology by Dr. John B. West is available freely online39, 40.

One of the simplest activities that can be routinely used is one that has been demonstrated by Rodenbaugh *et al*. who described the cohesive forces of the intrapleural space using microscope slides and a few drops of water41. This simulated the action of the pleural fluid that permitted the pleural layers to slide over one another, but at the same time resisted the separation of the two layers of the pleura.

The basic properties of gases have been demonstrated by Collins and DiCarlo using balloons, water and cans42. Haddad *et al*. have described a novel experiment to illustrate Laplace’s law43. In this simple experiment, an object was suspended on a sheet held up by two students. The distance between the two students was varied and the tension needed was used to demonstrate Laplace’s law. Laplace’s law was also described by [Milorad Letić](http://advan.physiology.org/search?author1=Milorad+Leti%C4%87&sortspec=date&submit=Submit), who used balloons to help students feel the tension developed44.

Through the years different activities have been used to model ventilation and perfusion and the exchange of gases. Vander Baptisa has used a model comprising springs and syringes to simulate respiratory mechanics45. In this model springs were used to model the recoil forces produced by the lungs and the chest wall. The space between two plungers fitted within a barrel represented the pleural space. A simple model of the lung, chest wall and the pleural space has been designed by Sherman using a glass bottle, balloon and a syringe46. The glass bottle represented the chest wall and the balloon represented the lungs. The space between the balloon and the bottle was filled with water, mimicking the fluid-filled pleural space. The syringe connected to the glass bottle served to change the water pressure and thus represented the respiratory muscles46, 45.

The article by Kuebler *et al*. describes the construction of a two component model to teach respiratory mechanics. The model uses lung and chest wall models along with cylinders, manometers, syringes and volumeter to teach the pressure-volume relationship during breathing This model may be modified by the readers to suit their teaching objective47.

Silva *et al*. have designed a simple model to explain the time constant of inflation and deflation of the respiratory system using two artificial lungs, plastic tubes, gauze and rubber bands. An increase in airway resistance was simulated by placing a gauze in the plastic tube. A decrease in the compliance of the lung was simulated by strapping the artificial lung with a rubber band48. The article by McCulloch describes a model made of rods and rubber bands to understand the recoil forces of the lung and the chest wall. He used this model to show active inspiration and passive expiration. The effect of diseases like fibrosis and emphysema on lung recoil could also be demonstrated with this model49. The balance of forces at the functional residual capacity has been described using a plastic bottle, a balloon and a rubber glove50. B Stockert has also described the balance of forces in the lungs using a salad tong and a rubber band51. This model can be used to demonstrate pulmonary fibrosis, an increase in compliance as well as the balance of forces at the functional residual capacity. This model also described the effects of conditions such as obesity and ankylosing spondylitis on the respiratory system52. A more elaborate and realistic model of the lung and chest wall has been described by Chinet to record the static parameters of the respiratory system. This model built using bellows, steel coils and manometers can record static pressure-volume relationships of the chest wall and lungs. This model can also explain pneumothorax and the changes that occur during obstructive lung diseases53.

Certain lung models have also enabled measurements and simulations of diseased states. The article by Giuliodori and DiCarlo describes the construction of a simple and inexpensive spirometer using a syringe. This model enables the students to measure lung volumes. Simulation of positive pressure ventilation as well as obstructive and restrictive diseases was possible54. Giuliodori and DiCarlo fitted a spirometer tube with a one-way valve having a small hole in the middle to simulate the breathing pattern of obstructive pulmonary disease. This modification would generate a spirogram that resembles obstructive pulmonary disease even when used by normal subjects. The one-way valve with a hole provided high resistance for airflow in one direction (expiration) and less resistance in the opposite direction (inspiration)55. DiCarlo *et al*. have used a tennis ball and a balloon for chest wall and lungs respectively and have generated the relaxation curves for the lungs, chest wall, and combined lung-chest wall by using pressure transducers. Students could easily understand the pulmonary compliance curves once they appreciate how the relaxation curves were generated56. Weissenberg and Lavy used a mercury manometer, a balloon and a tube filled with water to create pressure-volume curves57. This was used to illustrate compliance of the lungs.

The oxygen carrying capacity of the blood has been illustrated by Breckler *et al*. in a hands-on classroom activity using tubes filled with water and beads58. Subramani *et al*. have suggested the use of the O2- CO2 diagram as a tool to illustrate blood gas abnormalities59.

Simple illustrations aid in the explanation of diseased states. James Norton has developed a visual aid using two rectangular bars representing ventilation and perfusion. This was used to explain the concept of ventilation and perfusion, ventilation/perfusion mismatch, dead space ventilation and shunt flow60. [Kostianev](http://advan.physiology.org/search?author1=S.+Kostianev&sortspec=date&submit=Submit) and [Iluchev](http://advan.physiology.org/search?author1=D.+Iluchev&sortspec=date&submit=Submit) described a simple two dimensional oxygen map that can be used to represent different hypoxic conditions61.

An innovative approach to teach pulmonary physiology calculations has been described by Maron *et al*. where the students were asked to solve a ‘murder mystery’62. The students were asked to solve problems and identify the murderer using the physiological evidences uncovered by a detective in the mystery story.

Stephen E. DiCarlo in a ‘refresher course’ published in Advances in Physiology Education reviewed many of the above mentioned models related to respiratory physiology63.

**The Nervous System and special senses:** A simple exercise to facilitate the learning of brain anatomy has been described by Vanags *et al*. The students were asked to use a plastic shower cap and mark the brain areas on it64. Masters and Christensen have also developed a similar analogy using cauliflower to illustrate the structure and the function of the brain to the undergraduate and graduate students of health sciences65. They have used the similarity between the cauliflower and the brain to supplement the lectures. Various anatomical features of the brain were marked on the surface of the cauliflower. Herur *et al*. have described a process of using clay modeling to help students understand neurophysiology66. Play dough was used to make models of the sensory and motor tracts.

An article by [Giuliodori](http://advan.physiology.org/search?author1=Mauricio+J.+Giuliodori&sortspec=date&submit=Submit) and [Zuccolilli](http://advan.physiology.org/search?author1=Gustavo+Zuccolilli&sortspec=date&submit=Submit) describes an illustration of a neuronal synapse to teach temporal and spatial summation and the generation of action potential at the axon hillock. The illustration has divided the synaptic region into three distinctive zones, namely the input zone, integrative zone and conductive zone based on the difference in the presence of ligand and voltage gated ion channels67. Giuliodori and DiCarlo have described the use of an illustration to teach students about the difference in conduction velocity between myelinated and unmyelinated neurons68. The illustration shows that myelin sheath reduces length and surface area where depolarization occurs and that this leads to faster action potential propagation in a myelinated neuron.

Sircar and Tandon have used an analogy of a burning cigarette to describe nerve conduction. Various determinants of speed of impulse conduction in a nerve such as threshold potential, diameter of the nerve and myelination have been explained using this analogy69. Chan *et al*. have described a model in which electrical wires and switches are used to mimic the monosynaptic and polysynaptic reflex arcs70. The connection between the wires represented the synapses in a neural circuit.

Nayak and Soumya used a simple model using tomatoes and broomsticks to demonstrate different types of eye movements71. They used 3 broomsticks passing through the tomatoes perpendicular to each other. Rotating the tomatoes along the three axes of the broomsticks demonstrated abduction, adduction, elevation, depression, extorsion and intorsion.

Eblen-Zajjur has described a simple anatomical model of the eye using a opaque bulb as retina and a white Styrofoam hemisphere as sclera72. Coloured bulbs were used to mimic visual fields. Concepts like retinal projection of visual field, image inversion, and blind spot determination were explained to undergraduate graduate students using this model. Andrea Novicki has developed an exercise in which the students were asked to pass around empty and weighted paper cups to appreciate the sense of proprioception73.

**The excretory System:** The article by Richardson and Speck describes an illustration and model used to make students understand the concept of renal clearance. The authors have used the model consisting of beakers containing colored solutions and oil to introduce the concept of virtual volume to the students. They found that the understanding of the students about renal clearance improved after exposure to this model74.

**Acid Base and Electrolyte Physiology:** A simple model that can be used for students to identify common acid base disorders is the Willie’s box75. This was a tool developed by Dr. William T Lipscomb for helping understand the acid- base status of an individual. An online resource for learning electrolyte and acid base physiology has been developed by Davids *et al*.76 and is available for free access on the web.

**Miscellaneous :** The role of a counter current system in heat exchange was demonstrated using dialysis tubing by Loudon *et al*.77. The role of fat and air as thermal insulators has been illustrated using mittens, bubble wrap and vegetable shortening78.

As an alternative to using microscopy, virtual microscopy using an online library of microscopy slides has been found to be appreciated by students79.

The teaching of ethics in exercise physiology was described by David Senchina80. An exercise physiology experiment was filmed, and this film was shown to students with questions on ethics.

Cendan and Lok have reviewed the use of virtual patients for teaching. The various virtual patient technologies as well as free content have been described81.

**Conclusion:** The journal advances in Physiology education is indeed a treasure trove of physiology resources. It provides a forum for educators to publish interesting ideas, innovations, teaching methods and illustrations. It is freely accessible online. The authors hope that this review will help Indian Physiologists contribute many novel ideas to physiology education as well as utilize many of these easy to construct models and activities in their own teaching.

**References**

1. Haddad H, Baldo MVC. Teaching diffusion with a coin. Advan in Physiol Edu. 2010 Sep 1;34(3):156–7.

2. Honig A, Oppermann H, Budweg C, Goldbecher H, Freyse EJ. Demonstration of temperature dependence of Na(+)-K+ pump activity of human blood cells. Advan in Physiol Edu. 1994 Jun 1;266(6):S10.

3. Sircar SS. A hydrostatic model of membrane potential. Advan in Physiol Edu. 1994 Dec 1;267(6):S77.

4. Carvalho H. A group dynamic activity for learning the cardiac cycle and action potential. Advan in Physiol Edu. 2011 Sep 1;35(3):312–3.

5. Milanick M. Changes of membrane potential demonstrated by changes in solution color. Advan in Physiol Edu. 2009 Sep 1;33(3):230–230.

6. Moran WM, Denton J, Wilson K, Williams M, Runge SW. A simple, inexpensive method for teaching how membrane potentials are generated. Advan in Physiol Edu. 1999 Dec 1;277(6):S51.

7. Nolan WF. A problem-solving approach to teaching electrochemical driving force to undergraduates. Advan in Physiol Edu. 1990 Dec 1;259(6):S1.

8. Cardozo DL. A model for understanding membrane potential using springs. Advan in Physiol Edu. 2005 Dec 1;29(4):204–7.

9. Krontiris-Litowitz J. Using Manipulatives to Improve Learning in the Undergraduate Neurophysiology Curriculum. Advan in Physiol Edu. 2003 Sep 1;27(3):109–19.

10. Gamba G. Analogy for Explaining Intermediate Metabolism. Advan in Physiol Edu. 2003 Sep 1;27(3):156–7.

11. Stavrianeas S, Silverstein T. Teaching Glycolysis Regulation to Undergraduates Using an Electrical Power Generation Analogy. Advan in Physiol Edu. 2005 Jun 1;29(2):128–30.

12. DoHarris L, Giesler A, Humber B, Sukumar A, Janssen LJ. Molecular motors: how to make models that can be used to convey the concept of molecular ratchets and thermal capture. Advan in Physiol Edu. 2011 Jun 1;35(2):213–8.

13. Baptista V. Starting Physiology: Understanding Homeostasis. Advan in Physiol Edu. 2006 Dec 1;30(4):263–4.

14. Jittivadhna K, Ruenwongsa P, Panijpan B. Hand-held model of a sarcomere to illustrate the sliding filament mechanism in muscle contraction. Advan in Physiol Edu. 2009 Dec 1;33(4):297–301.

15. Giuliodori MJ, Lujan HL, Briggs WS, Palani G, DiCarlo SE. Hooke’s law: applications of a recurring principle. Advan in Physiol Edu. 2009 Dec 1;33(4):293–6.

16. Buono M, Kolkhorst F. Estimating ATP resynthesis during a marathon run: a method to introduce metabolism. Advan in Physiol Edu. 2001 Jun 1;25(2):70–1.

17. Easton DM. Muscle chamber with strain gauge adapted for isotonic/isometric recording. Advan in Physiol Edu. 1996 Jun 1;270(6):S29.

18. Bhaskar A, Tharion E, Devasahayam SR. Computer-Based Inexpensive Surface Electromyography Recording for a Student Laboratory. Advan in Physiol Edu. 2007 Jun 1;31(2):242–3.

19. Kumar S. An analogy for explaining erythrocyte fragility: concepts made easy. Advan in Physiol Edu. 2002 Jun 1;26(2):134–5.

20. Lellis-Santos C, Giannocco G, Nunes MT. The case of thyroid hormones: how to learn physiology by solving a detective case. Advan in Physiol Edu. 2011 Jun 1;35(2):219–26.

21. Swain DP. The beaver pond analogy of blood glucose control. Advan in Physiol Edu. 1999 Jun 1;276(6):S69.

22. Passos RM, Sé AB, Wolff VL, Nobrega YKM, Hermes-Lima M. Pizza and pasta help students learn metabolism. Advan in Physiol Edu. 2006 Jun 1;30(2):89–93.

23. B SN. The Blanket Method: a Novel Method of Teaching Peritoneal Relations of Female Reproductive Organs. Advan in Physiol Edu. 2006 Jun 1;30(2):95–6.

24. Swain DP. The water-tower analogy of the cardiovascular system. Advan in Physiol Edu. 2000 Dec 1;24(1):43–50.

25. Russ RD. A simple model to demonstrate the isovolumic contraction and rapid ejection phases of the cardiac cycle. Advan in Physiol Edu. 1998 Dec 1;275(6):S246.

26. Rodenbaugh DW, Collins HL, Chen CY, DiCarlo SE. Construction of a model demonstrating cardiovascular principles. Advan in Physiol Edu. 1999 Dec 1;277(6):S67.

27. Giuliodori MJ, Lujan HL, DiCarlo SE. Classic experimentation and working models for engaging and inspiring students. Advan in Physiol Edu. 2012 Mar 1;36(1):63–4.

28. Fry JR, Burr SA. A double-blind atropine trial for active learning of autonomic function. Advan in Physiol Edu. 2011 Dec 1;35(4):438–44.

29. Collins HL, DiCarlo SE. An educational tool for understanding the cardiovascular changes associated with diabetes. Advan in Physiol Edu. 1995 Dec 1;269(6):S4.

30. Pressley TA, Limson M, Byse M, Matyas ML. The Healthy Heart Race: a short-duration, hands-on activity in cardiovascular physiology for museums and science festivals. Advan in Physiol Edu. 2011 Sep 1;35(3):275–9.

31. Belušič G, Zupančič G. Singing greeting card beeper as a finger pulse sensor. Advan in Physiol Edu. 2010 Jun 1;34(2):90–2.

32. Hiebert SM, Burch E. Simulated Human Diving and Heart Rate: Making the Most of the Diving Response as a Laboratory Exercise. Advan in Physiol Edu. 2003 Sep 1;27(3):130–45.

33. Pontiga F, Gaytán SP. An experimental approach to the fundamental principles of hemodynamics. Advan in Physiol Edu. 2005 Sep 1;29(3):165–71.

34. Bhaskar A, Vinod A. Demonstration of the Origin of ECG Waves. Advan in Physiol Edu. 2006 Sep 1;30(3):128–128.

35. Lawson DM. A model for visualizing fluid handling by the gastrointestinal tract. Advan in Physiol Edu. 2003 Jun 1;27(2):87–8.

36. Odenweller CM, Hsu CT, DiCarlo SE. Educational card games for understanding gastrointestinal physiology. Advan in Physiol Edu. 1998 Dec 1;275(6):S78.

37. LePard KJ. Student Demonstration of Relationship Between Intestinal Slow Waves and Phasic Contractions. Advan in Physiol Edu. 2005 Jun 1;29(2):131–2.

38. Abdulkader F, Azevedo-Martins AK, Miranda M de A, Brunaldi K. Chewing over physiology integration. Advan in Physiol Edu. 2005 Mar 1;29(1):51–3.

39. West JB. A Web-based course of lectures in respiratory physiology. Advan in Physiol Edu. 2011 Sep 1;35(3):249–51.

40. West JB. Internet-based course on pulmonary pathophysiology. Advan in Physiol Edu. 2012 Mar 1;36(1):1–2.

41. Rodenbaugh DW, Collins HL, Dicarlo SE. A simple model for understanding cohesive forces of the intrapleural space. Advan in Physiol Edu. 2003 Mar 1;27(1):42–3.

42. Collins HL, DiCarlo SE. Simple, Inexpensive Classroom Experiments for Understanding Basic Gas Laws and Properties of Gases. Advan in Physiol Edu. 2003 Dec 1;27(4):244–244.

43. Haddad H, Brito I. Feeling Laplace. Advan in Physiol Edu. 2011 Mar 1;35(1):97–8.

44. Letić M. Feeling wall tension in an interactive demonstration of Laplace’s law. Advan in Physiol Edu. 2012 Jun 1;36(2):176–176.

45. Baptista V. A qualitative analogy for respiratory mechanics. Advan in Physiol Edu. 2010 Dec 1;34(4):239–43.

46. Sherman TF. A simple analogue of lung mechanics. Advances in Physiology Education. 1993 Dec 1;265(6):S32 –S34.

47. Kuebler WM, Mertens M, Pries AR. A two-component simulation model to teach respiratory mechanics. Advances in Physiology Education. 2007 Jun 1;31(2):218 –222.

48. Silva CAM e, Ventura CEG dos S. A Simple Model Illustrating the Respiratory System’s Time Constant Concept. Advan in Physiol Edu. 2006 Sep 1;30(3):129–30.

49. McCulloch P. A Simple Model Illustrating the Balancing Forces of Lung and Chest Wall Recoil. Advances in Physiology Education. 2004;28(3):125 –127.

50. Kanthakumar P, Oommen V. A simple model to demonstrate the balance of forces at functional residual capacity. Advan in Physiol Edu. 2012 Jun 1;36(2):170–1.

51. Stockert B. Pulmonary ventilation teaching aid. Advan in Physiol Edu. 2003 Mar 1;27(1):41–2.

52. Stockert B. Pulmonary ventilation teaching aid: part 2. Advan in Physiol Edu. 2003 Jun 1;27(2):86–7.

53. Chinet AE. Chest-lung statics: a realistic analog for student laboratory. Advan in Physiol Edu. 1989 Dec 1;257(6):S9.

54. Giuliodori MJ, DiCarlo SE. Simple, Inexpensive Model Spirometer for Understanding Ventilation Volumes. Advan in Physiol Edu. 2004 Mar 1;28(1):33–33.

55. Giuliodori MJ, DiCarlo SE. An Improved Model for Simulating Obstructive Lung Disease. Advan in Physiol Edu. 2008 Jun 1;32(2):167–167.

56. DiCarlo, Collins HL, Rodenbaugh DW. Experiment to Help Students Understand Pulmonary Compliance. Advances in Physiology Education. 2002 Jun 1;26(2):135–6.

57. Weissenberg S, Lavy R. Pressure-Volume Curve and Compliance of a Balloon: a Simulation. Advan in Physiol Edu. 2003 Dec 1;27(4):244–5.

58. Breckler J, Yu JR. Student responses to a hands-on kinesthetic lecture activity for learning about the oxygen carrying capacity of blood. Advan in Physiol Edu. 2011 Mar 1;35(1):39–47.

59. Subramani S, Kanthakumar P, Maneksh D, Sidharthan A, Rao SV, Parasuraman V, *et al*. O2-CO2 diagram as a tool for comprehension of blood gas abnormalities. Adv Physiol Educ. 2011 Sep;35(3):314–20.

60. Norton JM. A visual aid for teaching ventilation-perfusion relationships. Advan in Physiol Edu. 2000 Dec 1;24(1):38–42.

61. Kostianev S, Iluchev D. Two-Dimensional Oxygen Map For Graphic Representation of Different Hypoxic Conditions. Advan in Physiol Edu. 2003 Dec 1;27(4):242–3.

62. Maron MB, Bosso FJ. “Murder mystery” for student practice of pulmonary physiology calculations. Advan in Physiol Edu. 1991 Dec 1;261(6):S3.

63. DiCarlo SE. Teaching alveolar ventilation with simple, inexpensive models. Advances in Physiology Education. 2008;32(3):185 –191.

64. Vanags T, Budimlic M, Herbert E, Montgomery MM, Vickers T. Showercap Mindmap: a spatial activity for learning physiology terminology and location. Advan in Physiol Edu. 2012 Jun 1;36(2):125–30.

65. Masters J, Christensen M. Please pass the cauliflower: a recipe for introducing undergraduate students to brain structure and function. Advan in Physiol Edu. 2000 Dec 1;24(1):22–9.

66. Herur A, Kolagi S, Chinagudi S, Manjula R, Patil S. Active learning by play dough modeling in the medical profession. Advan in Physiol Edu. 2011 Jun 1;35(2):241–3.

67. Giuliodori MJ, Zuccolilli G. Postsynaptic Potential Summation and Action Potential Initiation: Function Following Form. Advan in Physiol Edu. 2004 Jun 1;28(2):79–80.

68. Giuliodori MJ, DiCarlo SE. Myelinated Vs. Unmyelinated Nerve Conduction: A Novel Way of Understanding the Mechanisms. Advan in Physiol Edu. 2004 Jun 1;28(2):80–1.

69. Sircar SS, Tandon OP. Teaching nerve conduction to undergraduates: the “traveling flame” analogy revisited. Advan in Physiol Edu. 1996 Jun 1;270(6):S78.

70. Chan V, Pisegna JM, Rosian RL, DiCarlo SE. Construction of a model demonstrating neural pathways and reflex arcs. Advan in Physiol Edu. 1996 Dec 1;271(6):S14.

71. Nayak S, Soumya KV. A simple model to demonstrate the movements and the axes of the eyeball. Advan in Physiol Edu. 2009 Dec 1;33(4):356–7.

72. Eblen-Zajjur A. A simple analog of visual field retinal projection. Advan in Physiol Edu. 1997 Jun 1;272(6):S15.

73. Novicki A. Proprioception: Confronting Prior Knowledge. Advan in Physiol Edu. 2005 Dec 1;29(4):210–1.

74. Richardson D, Speck D. Addressing students’ misconceptions of renal clearance. Advan in Physiol Edu. 2004 Dec 1;28(4):210–2.

75. Dietz JR. Using Willie’s acid-base box for blood gas analysis. Advan in Physiol Edu. 2011 Dec 1;35(4):454–5.

76. Davids MR, Chikte UME, Halperin ML. Development and evaluation of a multimedia e-learning resource for electrolyte and acid-base disorders. Advan in Physiol Edu. 2011 Sep 1;35(3):295–306.

77. Loudon C, Davis-Berg EC, Botz JT. A laboratory exercise using a physical model for demonstrating countercurrent heat exchange. Advan in Physiol Edu. 2012 Mar 1;36(1):58–62.

78. Limson M, Krontiris-Litowitz J, Ortiz RM, Pressley TA, Matyas ML. The insulation bag: learning thermoregulation through a “hands-in” activity. Advan in Physiol Edu. 2012 Mar 1;36(1):65–7.

79. Anyanwu GE, Agu AU, Anyaehie UB. Enhancing learning objectives by use of simple virtual microscopic slides in cellular physiology and histology: impact and attitudes. Advan in Physiol Edu. 2012 Jun 1;36(2):158–63.

80. Senchina DS. Video laboratories for the teaching and learning of professional ethics in exercise physiology curricula. Advan in Physiol Edu. 2011 Sep 1;35(3):264–9.

81. Cendan J, Lok B. The use of virtual patients in medical school curricula. Advan in Physiol Edu. 2012 Mar 1;36(1):48–53.

**Disclosure:** No conflicts of interest, financial or otherwise are declared by the authors.