Learning Physiology Made Simple And Fun: A Review of Teaching Resources From The Journal Advances In Physiology Education

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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

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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 toss[1]. 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 cocks[3]. 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 potential[5]. 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 membrane[6]. 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 membrane[7].

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 potential[8].

Johanna Krontiris-Litowitz 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 membrane[9].

Geraldo Gamba has used an analogy of the monthly paycheck, banking as well as personal expenses to illustrate the concepts involved in intermediate metabolism[10]. 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 direction[12].

Baptista describes a pictorial analogy of cell culture to teach the students about the concept of homeostasis[13]. 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 springs[14]. 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 law[15]. 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 pathways[16].

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 recordings[17].

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 signals[18].

Blood and Body Fluids: A simple exercise to illustrate the concept of osmotic fragility of erythrocytes has been described by Sanjay Kumar[19]. 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 case[20].

The control of glucose levels in the blood has been illustrated by David Swain using a beaver and pond analogy[21]. 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 systems[23]. 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 Russ[25]. Rodenbaugh *et al*. have developed a cardiovascular model using inexpensive materials such as syringes, tubing and balloons[26].

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 cycle[4].
Giuliodori *et al*. have described a method to construct simple valves using tubings and balloons[27]. 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 subjects[28]. 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 individuals[29]. 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 tubing[30]. 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 card[31]. 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 Burch[32]. Pontiga and Gaytán have used an experimental approach to explain basic concepts in hemodynamics[33]. 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 waveform[34].

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 tract[35]. 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 with[36].

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 contraction[37].

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 control[38].

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 online[39, 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 water[41]. 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 cans[42]. Haddad *et al*. have described a novel experiment to illustrate Laplace's law[43]. 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, who used balloons to help students feel the tension developed[44].

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 mechanics[45]. 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 syringe[46]. 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 muscles[46, 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 objective[47].

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 band[48]. 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 model[49]. The balance of forces at the functional residual capacity has been described using a plastic bottle, a balloon and a rubber glove[50]. B Stockert has also described the balance of forces in the lungs using a salad tong and a rubber band[51]. 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 system[52]. 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 diseases[53].

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 possible[54]. 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 generated[56]. Weissenberg and Lavy used a mercury manometer, a balloon and a tube filled with water to create pressure-volume curves[57]. 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 beads[58]. Subramani *et al*. have suggested the use of the O_2- CO_2 diagram as a tool to illustrate blood gas abnormalities[59].

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 flow[60]. Kostianev and Iluchev described a simple two dimensional oxygen map that can be used to represent different hypoxic conditions[61].
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 physiology[63].

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 it[64]. 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 sciences[65]. 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 neurophysiology[66]. Play dough was used to make models of the sensory and motor tracts.

An article by Giuliodori and Zuccolilli 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 channels[67]. Giuliodori and DiCarlo have described the use of an illustration to teach students about the difference in conduction velocity between myelinated and unmyelinated neurons[68]. 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 analogy[69]. Chan *et al*. have described a model in which electrical wires and switches are used to mimic the monosynaptic and polysynaptic reflex arcs[70]. 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 movements[71]. 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 sclera[72]. 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 proprioception[73].

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 model[74].

Acid Base and Electrolyte Physiology: A simple model that can be used for students to identify common acid base disorders is the Willie's box[75]. 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 shortening[78].

As an alternative to using microscopy, virtual microscopy using an online library of microscopy slides has been found to be appreciated by students[79].

The teaching of ethics in exercise physiology was described by David Senchina[80]. 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 described[81].

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.

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