Inexpensive Hands-On Activities to Reinforce Basic Physiological Principles: Details of a Soda Bottle Nephron Model.

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Inexpensive Hands-On Activities to Reinforce Basic Physiological Principles: Details of a Soda Bottle Nephron Model

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Abstract
For many reasons, physiological aspects of anatomy and physiology laboratories are often presented as simulations. While simulations effectively convey concepts, hands-on activities promote more active student engagement. Recycled soda bottles, supplemented with other inexpensive readily available supplies, can be used to create working models illustrating concepts such as filtration at the glomerulus with reabsorption from the renal tubules, heart valve regulation of flow direction, negative pressure of inhalation, and fluid conduction of sound waves in the inner ear. These activities demonstrate basic biological properties, and allow for more in-depth student exploration resulting in enhanced cognition. The activities are well received by students who find them to be informative and fun. In this article, readers are guided through the construction of a model nephron with detailed step-by-step instructions and assessment tools. https://doi.org/10.21692/haps.2018.017

Key Words: nephron model, inexpensive laboratory, renal physiology, hands-on activity, simulation

Introduction
Life-long learning marks student success, which is the prime goal of teaching at all levels of education. Active engagement helps students develop critical thinking and problem solving skills essential in life-long learning. To promote these higher levels of learning, use of computer-assisted simulations and data analysis have become widely popular in medicine and life sciences (Lateef 2010, Hallow and Gebremichael 2017). Computer-assisted simulations and data acquisition systems, however, are often expensive and they leave physiological concepts in abstract form.

Simulations and model systems are most valuable when combined with actual experiments (Lewis 1989). This has been demonstrated at many levels of education. At the pre-college level, Yun *et al*. (2017) developed a model to examine hydrostatic filtration in the glomerulus. This was a well-received small group activity deemed successful due to its hands-on nature. Similar success has been observed at undergraduate institutions. For example, Krontiris-Litowitz (2003) demonstrated improved student grades with the use of manipulatives to demonstrate movement through membranes. Likewise, Rios and Bonfim (2013) found improved student engagement and enthusiasm when using model-building activities to explain sarcomere contraction. Carvalho and Giffen (2014) devised a laboratory activity focusing on renal cell models using small color-coded cardstock pieces that represented major molecular transporters and channels. The activity was well received and students reported enhanced understanding of renal physiology. At the graduate level, medical school students have exhibited a significant increase in test scores following hands-on modeling of obstructive and restrictive airways (Jamison and Stewart 2011), improved understanding of atherosclerosis using a mechanical device to alter blood vessel diameter (Almeida and Lima 2013), and improved performance following use of cost-effective hands-on simulations of neonatal intubation (Bruno and Glass 2016).

The hands-on soda bottle science models presented in this paper, and in the accompanying website-accessible documents, are easy to construct using inexpensive, readily available materials. Students work in small groups to apply their conceptual knowledge of renal, cardiovascular, respiratory, and auditory physiology from the laboratory to reinforce the concepts learned in the lecture setting. Four activities have been developed (Motz *et al*. 2016): the nephron model described in this paper, a heart valve model, a model of the lung, and a model of the ear. All of the models are available on the HAPS website at hapsweb.org **HERE**. Each activity description includes: an overview, learning objectives, materials, directions for assembly of the model, the procedure for the activity, and assessment questions.

Soda-bottle labs have been used by the authors as supplementary add-ons to standard laboratories, using models, dissections, wet-laboratory activities, or computer-assisted experimentations. These activities have been used over the past twenty years in anatomy and physiology laboratories first at a community college and, in the past ten years, at a four-year institution. The nephron and heart models have also been included for the last two years in medical physiology laboratories.

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The nephron model helps to facilitate true understanding of difficult physiological concepts such as glomerular filtration and renal reabsorption. Students are enthusiastically engaged during model construction and associated exercises. They remain engaged during critical analytical discussions of the results of the activity and the related physiological concepts they have learned. The dynamic, visual nature of the model enhances the static learning of renal physiology gained in lectures. Furthermore, students can manipulate the model to mimic abnormal functioning.

Materials and Methods

Soda Bottle Science: The Nephron.

The nephron model demonstrates glomerular filtration pressure, tubular reabsorption, and the relationship between blood, filtrate, renal extracellular fluid, and peritubular capillaries.

Time required

It takes approximately 15 minutes to set up this exercise and 5 minutes to run.
Once set up, the model can be easily modified to demonstrate changes in filtration membrane permeability and filtration pressure.

Learning Objectives

In conducting this laboratory activity, the student will:

1. Review major parts of a nephron. **HAPS outcomes module P 2.3a.**
2. Demonstrate the passage of materials through a filtration membrane. **HAPS outcomes module P 3.2 a, b, e.**
3. Understand the properties of the filtration membrane's effects on glomerular filtration. **HAPS outcomes module P 3.2e.**
4. Demonstrate reabsorption of materials from filtrate into the bloodstream. **HAPS outcomes module P 3.3d.**
5. Demonstrate the production of urine. **HAPS outcomes module P 3.1, 3.7.**

Overview

The nephron uses multiple processes to clean the blood. Blood is represented in this model by a yellow fluid (food color in vinegar solution) with small particles such as sand or glitter representing proteins, and larger particles such as red and white beads representing blood cells. Having different sized particles allows for demonstration of filtration by size (see Table 1).

Glomerular filtration uses blood hydrostatic pressure to push the blood through the filtration membrane. In the model, blood pressure is represented by gravity and a paper towel is used to represent the normal filtration membrane, which will filter by size. Replacing the filter paper with a fine mesh will allow passage of "proteins" whereas netting will pass "cells", demonstrating abnormal filtration. In contrast, a membrane less permeable than paper towels will result in decreased filtration volume, decreasing flow rate through the "nephron tubule" and decreasing production of urine over time.

The renal tubule adjusts the blood's water, salt, and glucose levels through the processes of reabsorption and secretion, resulting in a change both tubular and extracellular fluid volumes and concentrations. In this model, reabsorption is represented by diffusion through a permeable membrane "tubule". Fluid diffusing across the membrane has an accompanying colorimetric change (facilitated by a pH indicator dye) that represents the reabsorption of plasma constituents into the extra cellular fluid (ECF). Overflow of the fluid from the soda bottle kidney tissue into the collecting tray represents return of water and nutrients to the blood.

The fluid remaining in the renal tubule is eliminated as urine. This is demonstrated in this model by having a yellow colored fluid leave the renal tubule to drain into another container that represents the urinary bladder. Note that if the filter paper is replaced with more permeable netting, "proteins" or "cells" will be present in the final urine to demonstrate diseased states.

Table 1. Corresponding model and nephron components

Model Component	**Nephron Component**
Inverted 2-liter bottle top	Glomerular capsule
Paper towel	Filtration membrane
Vinegar	Blood plasma
Glitter	Large blood proteins
Solution in 2-liter bottle	Interstitial fluid (ECF) surrounding the renal tubule
3-liter bottle bottom or other	Peritubular capillaries
Small plastic container	Urinary bladder

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Assemble the model

Using Figure 1 as a guide, follow the step-by-step instructions below:

1. Cut the top off of a 2-liter soda bottle an inch below where the sides become parallel with each other. Note the black, broken-line marks on the 2-liter soda bottle (Figure 1A).
2. Take the cut-off top of the bottle and slip one end of a fabric tube over the mouth of the soda bottle and secure it in place with a twist tie. [We made several tubes out of scrap materials such as nylon and felt, as well as cotton socks, to give students varying permeabilities to experiment with.] (Figure 1B)
3. Cut a 1½" square in the side of the bottom part of the bottle which is 2 ½" from the bottom. Note the black broken line marks on the 2-liter soda bottle (Figure 1A).

For steps 4-11, refer to Figure 1C.

4. Pour water into the bottom of the 2-liter bottle up to, but not overflowing the hole.
5. Add two drops of a pH indicator into this water. Any standard pH indicator solution such as phenolphthalein or 1% Methyl red can be used. Alternatively, a red cabbage indicator solution can be made by boiling red cabbage in water for 1 hour and straining. The pH indicator should turn red when acidified.
6. Invert the top of the bottle with the nylon tube attached into the bottom of the bottle. The top of the bottle will represent Bowman's capsule, and the bottom of the bottle will contain the ECF that surrounds Bowman's capsule and the nephron loop.
7. Immerse several inches of nylon tubing into the water containing the pH indicator. Pull the end through the square hole that you cut.
8. Fold a piece of paper towel into a funnel so that it fits into the "Bowman's Capsule" (upside-down bottle top). This filter paper represents the filtration membrane.
9. Cut the bottom 2½" off of a plastic container large enough to hold the 2-liter bottle (a 3-liter bottle will work well, as does the top of a take-out container which is used in Figure 1). This larger container represents the peritubular capillaries.
10. Put the 2-liter bottle bottom containing indicator dye solution into the larger plastic container. When the model is active, fluid in the tubing (tubular urine) will be "absorbed" into the solution in the 2-liter bottle, thus increasing the ECF volume. Since water was filled to the level of the cut hole, a small amount of the fluid will spill over from the 2-liter bottle (representing the reabsorbed nutrients and water) into the larger container such as the take out lid used in Figure 1, which represents the peritubular capillaries.
11. Arrange the open end of the nylon tubing so it will drain into an additional plastic container which is cut to the same level and which represents the urinary bladder.

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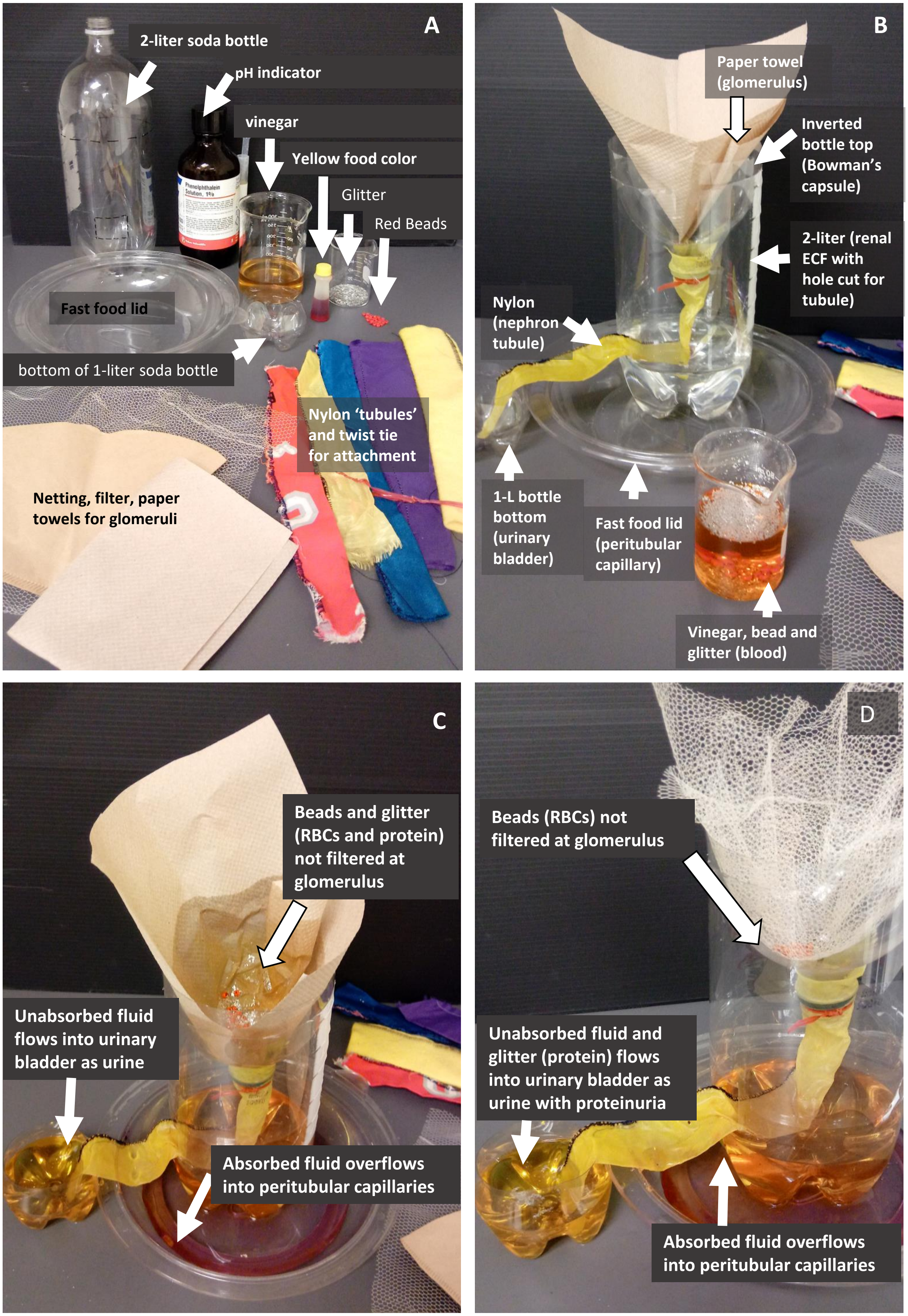

Figure 1. Guide for step-by-step instructions for nephron model

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Conduct the Activity

It is recommended that the instructor discuss which parts of the model represent which parts of the nephron prior to performing the activity. Alternatively, the instructor may want students to generate this information by exploring the materials.

1. Prepare the "blood": mix vinegar, yellow food coloring, red beads, and glitter.
2. Gently swirl, then pour the "blood" into the paper towel-lined "Bowman's capsule.
3. Record the time it takes for the blood to pass through the paper towel filtration membrane.
4. Make and record observations on what material stays in the paper towel, and what material goes through it.
5. Note the relative ease of flow of fluid through the wall of the tubing. The type of tubing chosen will have variable permeability. Thus, a tube made from a nylon stocking will be more permeable than one made out of felt, which will, in turn, have greater permeability than a tube made of rip-stop nylon. The tube can be made from any varied group of scrap fabrics to achieve this range of permeability
6. Observe and record any changes that occur as this fluid is "reabsorbed" from the "tubule" into the "ECF".
7. Observe the overflow of fluid from 2-liter bottle into the 3-liter container representing the peritubular capillaries.
8. Observe the flow of the fluid remaining in the nylon tubing into the container representing the urinary bladder.
9. Have students repeat the experiment using the model they have constructed and altering the procedure as follows:

   a) Alter the filtration membrane to demonstrate nephrotic and nephritic disorders by using more and less porous alternatives such as old stockings, cheesecloth, mesh or filter paper.

   b) Alter "reabsorption" by switching the "rip-stop" nylon with alternative materials to represent alterations of transmembrane transport.

   c) Alter the amount of vinegar mixture poured into the funnel to represent high blood pressure or decreased renal flow.

Assessment questions can be added to student laboratory report requirements to demonstrate understanding of material (see Table 2).

Table 2. Potential assessment activities/questions

If Table 1 is not provided to students, students could be asked to generate it.
What materials remained in the paper towel? Why? How does this relate to what happens during filtration?
What is the purpose of the pH indicator in the water? What does the change in the color of the water indicate has happened?
If students try alternate filtration membranes, they should compare the times required for passage through the membranes. The data should be accompanied by discussion.
In some kidney diseases, inflammation can block the filtration membrane, making it difficult for filtrate to form. How does this difference relate to the original paper towel and the filter paper?
Some kidney diseases cause the glomerular membrane to deteriorate. The resulting enlarged filtration slits allow larger proteins to enter the nephron. Since there are no recovery mechanisms in place for these proteins, they are lost in the urine. How does this relate to the use of cheesecloth versus the original paper towel in the results obtained? How would the rate of urine entering the bladder differ?
In a stress situation, the sympathetic nervous system would decrease the flow to the kidney. How does decreasing the amount of vinegar used affect renal function?

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Discussion and Conclusion

Anatomy and physiology laboratories at the authors' institution are conducted as a series of stations where students complete an activity at each station. This permits students to move at their own pace and is especially conducive to laboratories in which there are insufficient models/slides/computers to have one at each station. Each student group thus explores the soda bottle model independently of the rest of the class.

When this nephron model was used to supplement the didactic renal physiology, 100% of student investigators understood the representation of the filtration membrane and Bowman's capsule as well as implications of differential permeability of the membrane. However, fewer than 75% of students were able to make physiological connections for the overflow into the larger container and for the colorimetric change without explicit instructor explanation, as evidenced by poor answers on lab reports for this item.

In actively constructing the model, students reinforce their anatomical knowledge of the nephron, as they are directed to draw correlations between model components and nephron segments. Students responded favorably to making the model and especially enjoyed evaluating the model as to where it correctly or incorrectly demonstrated physiological actions of the nephron (i.e. showing reabsorption but not secretion; or failing to demonstrate differentiation between parts of the nephron tubule).

Students, on the whole, enjoyed the opportunity to take ownership of the experiment. The ability to investigate independently by choosing which materials to utilize in a modified nephron model stimulated student curiosity. Because of this, the Soda Bottle models have greater potential for encouraging life-long learning than if only more traditional, less hands-on, activities are used.

Continual modernization and update of laboratory equipment can pose an economic challenge, which can be mitigated with creative use of low cost materials. Soda-bottle models are a hands-on laboratory learning tools that are inexpensive to construct, yet they greatly enhance interactive and collaborative small-group learning, critical and analytical thinking, problem solving, and effective communication skills.

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Dr. Vicki Abrams Motz and Dr. Rema G. Suniga, Associate Professors, and Dr. Jacqueline Runestad Connour, Assistant Professor, are faculty members in the Department of Biological and Allied Health Sciences, Ohio Northern University. Drs. Motz and Suniga team-teach a year-long Medical Physiology course geared toward pre-health professional Allied Health Science students. Drs. Motz and Connour team-teach in the Anatomy and Physiology full year sequence geared toward nursing and exercise physiology majors. Dr. Connour also teaches cadaver-based Human Anatomy laboratories. Dr. Suniga researches vasoactive substances, Dr. Motz is an ethnobotanist, and Dr. Connour examines mammalian morphometrics.

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