

From Development to Function: Hands-On & Inexpensive Clay Modeling of Mammalian Kidney Development



RECOMMENDATION

• Maricela Sanchez-Acevedo, Robert M. Kao



ABSTRACT

In light of the coronavirus disease 2019 (COVID-19), recent clinical research has demonstrated that severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) affects breathing and internal organs, especially the kidneys and liver function. It is evident that the kidneys are induced by the virus through the course of the medication treatments, such as the side effects that lead to kidney and liver damage. In order to scaffold kidney pathophysiology with normal kidney development and function in a virtual class or lab setting during the COVID-19 pandemic, we have developed a hands-on and cost-effective clay modeling teaching tool at the undergraduate level for learning about kidney anatomy and development. Given remote teaching, this innovative tool can be used to link the structure to molecular and cellular function through an easy hands-on model for both learning and teaching demonstration for all students.

Key Words: kidney development; inexpensive clay modeling toolkit; kidney function; SARS-CoV-2; COVID-19; kidney injury and repair.

○ Introduction

Engaging students during the novel coronavirus 2019 (COVID-19) pandemic is an ongoing challenge in life science education. Since March of 2020, instructors and students have shifted to virtual online class and lab settings. During these challenges, life science educators across K–16 teaching are facing uncertainty during these challenges times, including developing hands-on approaches in learning biology concepts outlined in *Vision and Change in Undergraduate Biology Education* (American Association for the Advancement of Science, 2011) and the National Research Council's Three Dimensional

Learning Framework (NGSS). During the COVID-19 pandemic, there is an important need to provide innovative home-based lab modeling of biological processes. Recently, science education research has investigated the role of clay modeling in anatomy dissections, as well as students' attitudes using clay modeling and anatomy dissections in high school and college settings (Grigg et al., 2020; Valliyate et al., 2012; Waters et al., 2005; Motoike et al., 2009; DeHoff et al., 2011; Chan & Cheng, 2011; and Khalil et al., 2005).

We have created an inexpensive clay modeling approach as an interactive learning and teaching tool for educators. Over the past two decades in life science education, there have been many examples of using hands-on origami approaches to clarify processes in embryo development (Tosney, n.d.; Tosney et al., n.d.) and to clarify topics on organ repair (Kao, 2014). In addition, inexpensive clay modeling tools can also help students use hands-on creativity

to help visualize the mammalian kidney; how the human body holds two kidneys; and the emphasis by the National Institute of Diabetes and Digestive and Kidney Diseases Health Information Center (2018) on the kidneys' main functions—to remove waste products and excess fluid, to regulate blood pressure, and to maintain hemoglobin blood levels. Finally, the inexpensive clay modeling can be integrated with key learning outcomes (Table 1) linked to the Three Dimensional Learning Framework (National Research Council, 2012) and *Vision and Change* (American Association for the Advancement of Science, 2011). With our integrated multidimensional framework linking renal physiology, kidney development, and SARS-CoV-2 (Figure 1), we present a step-by-step approach using a modified corn starch and lotion recipe to make the kidney clay model that can be integrated into lessons about anatomy, physiology, and development of the early nephron.

The hands-on kidney clay model can be used to integrate topics from developmental biology and about underlying conditions and symptoms of chronic kidney disease to engage students in real-world examples.

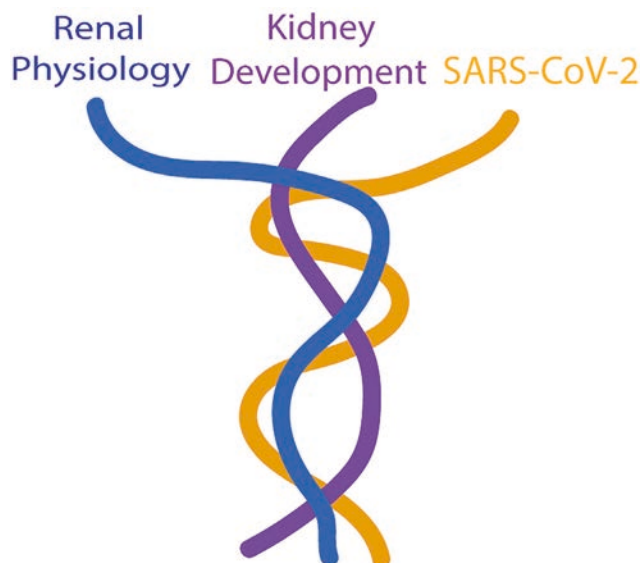


Figure 1. Integrated Framework Model. A model illustrated with three strands represented by SARS-CoV-2 (orange), kidney development (purple), and renal physiology (cyan) to show the integrated framework Three Dimensional Learning for the hands-on clay modeling approach.

○ Materials Used

- 1/2 cup corn starch
- 4 tablespoons lotion (e.g., Aveeno brand, but other skincare lotion brands will work)
- Markers of different colors

○ Clay Model Instructions

1. Mix all ingredients in a bowl until a soft working clay ball is formed.
2. Flatten the ball with the palm of the hand to form a kidney.
3. Use tips of fingers to demonstrate texture and lobes (Figures 2A and 2B).
4. Let air dry for approximately 20 minutes. In some cases, depending on temperature and humidity, it may require longer air-drying times. For activity during drying time, see section ahead “Lessons from Hands-on Kidney Clay Modeling within the Three-Dimensional Learning Framework” for possible discussions on kidney development and related topics on how and why acute kidney injury symptoms are associated with COVID-19.

Table 1. Linking Learning Objectives with the Three Dimensional Learning Framework and *Vision and Change* (2011).

		Learning Objectives in Kidney Development and Kidney Function Clay Model		
		Identify research questions on how molecules and cellular action are required for kidney development and disease.	Create a molecular and cellular model of the early developing nephron precursor (renal vesicle) during zebrafish and mammalian kidney development.	Develop a molecular and cellular model of how distal and proximal cell fates are generated in the nephron precursor (renal vesicle).
Three Dimensional Learning Framework	Scientific and Engineering Practices 1. Asking questions (for science)			
	Cross-cutting Concepts 1. Patterns 6. Structure and function			
	Disciplinary Core Ideas (Science) LS1: From molecules to organisms: structures and processes			
<i>Vision and Change</i> (2011)	Concepts: Structure and Function Information flow, exchange, and storage			

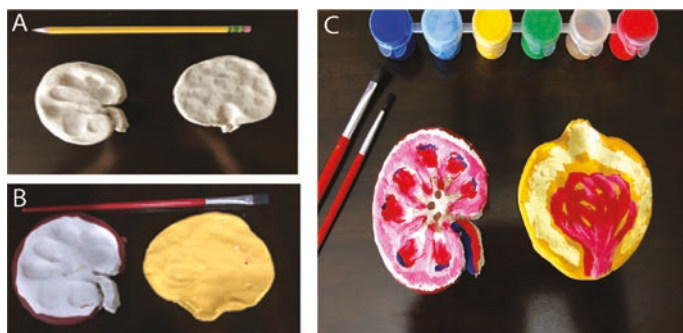


Figure 2. Inexpensive Clay Modeling of Mammalian Kidney Anatomy. (A–C) Examples of combining cornstarch and lotion clay with painting for illustrating mammalian kidney anatomy. (A) Examples of cornstarch and lotion clay models of transverse sections of mammalian adult kidneys. (B) Examples of molded cornstarch and lotion clay models. (C) Example of painted transverse sections of mammalian kidneys highlighting vasculature, cortex, medulla, and glomerulus.

5. Paint to demonstrate the anatomy and highlight areas of the mammalian kidney (Figure 2C). An alternative is to use labeling tape with toothpicks and to use a marker to highlight key cellular structures of the nephron.

In addition to modeling adult mammalian anatomy, we also explored clay modeling during early kidney development. We provided step-by-step instruction to illustrate key cell types that will form the future glomerulus, proximal tubule, loop of Henle, and distal tubule, shown in panel Figure 3A, from a key research article on nephron formation during early mouse kidney development by Georgas and colleagues (2009).

○ Clay Modeling of Early Mammalian Kidney Development Instructions

1. We combined the lotion clay to create a soft texture for the tip of the branching collecting duct (Figure 3A and 3B).
2. Next, we used dollar-store clay with a slightly harder clay texture to illustrate the future distal cells in green and the proximal cells in red (Figure 3C and 3D). The lotion clay with softer texture is sandwiched between the green and red clay pieces.
3. When describing the segments of the nephron precursor called the renal vesicle, mention to students that distal cells closest to the collecting duct will form a distal tubule that will connect to a collecting duct, while midsegment cells will give rise to a loop of Henle, and proximal cells will give rise to a proximal tubule and glomerulus.

○ Lessons from Hands-on Kidney Clay Modeling within the Three-Dimensional Learning Framework

We have presented an inexpensive and easy step-by-step approach to use hands-on clay modeling that can be used to engage students

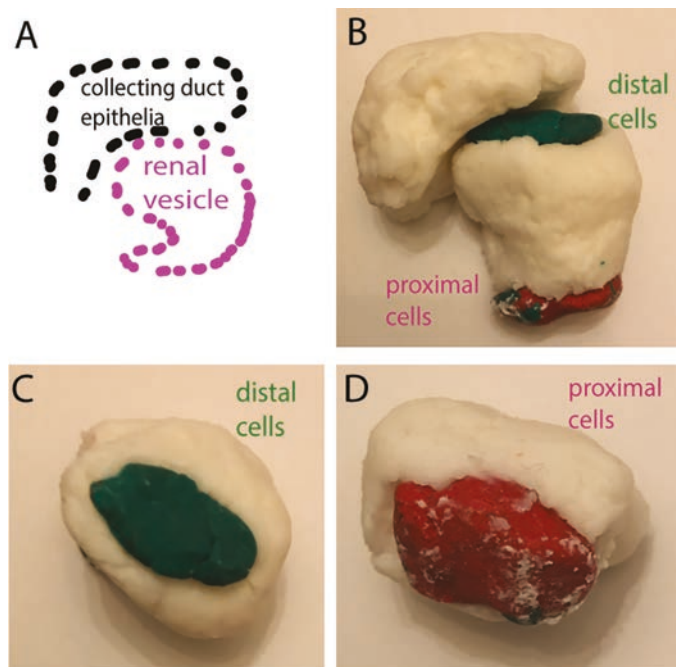


Figure 3. Inexpensive Clay Modeling of Key Cellular Types during Embryonic Mammalian Kidney Development. (A–D) Examples of combining cornstarch and lotion clay with painting for illustrating collecting duct epithelia and renal vesicle (nephron precursor) during early mammalian kidney development. (A) Example schematic of branching collecting duct epithelia tip (dotted line) juxtaposed to early renal vesicle (nephron precursor, magenta dotted line). (B) Inexpensive cornstarch and lotion clay (soft white texture) combined with recycled green and red clay from dollar store illustrating formation of distal cells (green) and proximal cells (red). (C) Distal view of a renal vesicle that will form a distal tubule of nephron and connect with collecting duct epithelia. (D) Proximal view of a renal vesicle that will form a glomerulus and podocytes and segments of distal tubules of a mature nephron.

not only in anatomy and development of the mammalian kidney but also to explore examples of acute and chronic kidney diseases. For example, the hands-on clay modeling can be used as a learning-model scaffold to integrate structure and function in anatomy and physiology settings. In addition, the hands-on kidney clay model can be used to integrate topics from developmental biology and about underlying conditions and symptoms of chronic kidney disease to engage students in real-world examples, such as SARS-CoV-2 causing COVID-19 symptoms. For example, “increased incidence of acute renal injury following COVID-19, which could due to the presence of SARS-CoV-2,” has been reported by Rismanbaf and Zarei (2020). We have come up with a teaching tool to easily demonstrate the physical damage on the kidney before and after treatment of diagnosed SARS-CoV-2.

While there is ongoing research on how and why patients living with COVID-19 may also display symptoms of kidney injury, we provide a recently review article by Legrand and colleagues (2021) on renal pathophysiology of COVID-19. As of July 2021, the exact molecular and cellular mechanisms of COVID-19 associated with acute kidney injury is still unknown. Recent studies have

observed damage to the tubular epithelium of the nephron, and inflammation within the kidney tissue and endothelial cell damage have been observed. Ongoing research is currently examining the role of anti-inflammation therapies using interleukin 6 (IL-6) receptor blockers. In summary, in light of the ongoing research, sharing with undergraduates how and why patients living with COVID-19 display symptoms of kidney injury can be used as an open-ended question to begin group discussions. For instance, one approach is to engage undergraduates to discuss the multidimensional aspects of pathophysiology and current therapies for treating acute kidney injury using a virtual Zoom or Jamboard format. In addition, starting discussions with open-ended question helps to engage undergraduates in the process of scientific investigations.

Another virtual summer research mentoring approach is to walk through and clarify mechanisms of mammalian kidney development using Zoom's annotation feature to draw out the process of nephron development. After clarifying kidney development, we then proceed with a journal club discussion on McKee and Wingert's *Journal of Visualized Experiments* article (2016) on nephro-neogenesis in zebrafish in response to injury. With students, we can discuss results and conclusions and brainstorm future directions as pathways to create a research proposal. Using a virtual summer research mentoring context, we can highlight examples of how recent research using applications of kidney development using mini kidneys, or organoids (Sperati, 2021), are currently being used to understand how SARS-CoV-2 infections can affect not only lung but also renal functions. Three podcast and video recordings were used to provide a preview before our discussions.

○ Summary

Overall, the mammalian kidney is very important in the study of SARS-CoV-2. The National Kidney Foundation-Harris Poll conducted a survey May 1–2, 2020, with a sample of 2039 US adults. Results indicate that 1 in 5 Americans know that COVID-19 could potentially cause renal damage. Foremost, the benefits of this interactive teaching tool for educators is not only to increase awareness in our community but also to educate on the mammalian kidney. This clay model can also be used to illuminate on nephro-neogenesis in zebrafish in response to injury (McKee and Wingert, 2016). In summary, the inexpensive kidney clay modeling can serve as a learning scaffold to integrate topics in anatomy, physiology, and developmental biology.

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MARICELA SANCHEZ-ACEVEDO is pursuing a National Science Foundation supplemental-grant-supported postbaccalaureate program at Heritage University, Toppenish, WA 98948. ROBERT M. KAO is an Associate Professor of Biology in the Science Department at the College of Arts and Sciences, Heritage University.