

Hands-on Activities to Engage Students in Muscle Cell Structure and Function

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ABSTRACT

Student-centered learning of biology concepts through hands-on tactile approaches is one of the important themes in inclusive and equitable STEM teaching. In our article, we describe the development of clay Velcro origami models for students to explore the molecular and cellular process of muscle fiber formation. We repurposed dollar store items and recyclable items used to construct a variety of textures in the clay Velcro model of early and late stages of muscle fiber formation. These hands-on activities are linked to the Next Generation Science Standards (NGSS) on using a model to explore the cell and structure changes to form a multinucleated muscle fiber or the formation of a syncytium. Finally, we also illustrate how students can utilize the clay Velcro model to make predictions if key molecules in cell fusion do not work during the process of syncytial formation during muscle fiber development.

Key Words: syncytium; cell fusion; Velcro clay models; access; integrative biology; inclusion.

○ Introduction

Providing tactile approaches to engage students who are blind is important in creating inclusive and equitable learning settings (Branch, 1942; Harjoe et al., 2023; Harris et al., 2022; Radavich, 2019; Watson & Bell, 2022). There have been many examples of innovative approaches to provide access to learning settings (Branch, 1942; Harjoe et al., 2023; Harris et al., 2022; Sanchez-Acevedo & Kao, 2022). Furthermore, tactile models also provide important equity-minded learning communities that connect storytelling, claywork, and Indigenous ways of knowing (Barajas-López, & Bang, 2018). Finally, there are several articles that highlight the importance of equity approaches to support blind and visually impaired learners in various contexts. For instance, in chemistry education, Hamann provides an innovative mindset to support blind and visually impaired students in chemistry classes and labs (Hamann, 2023). In order to incorporate equitable approaches for blind students to grasp biological concepts, several peer-reviewed articles provide examples of raised paper graphics and new policies for teachers to support blind students in the classroom (Ferreira &

Manis, 2022; Fraser & Maguvhe, 2008; Gardner, 1996; Kawooya et al., 2023).

Cell structure and function is one of the important core concepts in biology (Michael et al., 2017). We present two step-by-step hands-on activities that are aligned to the Next Generation Science Standards or NGSS (NGSS, 2013). In Table 1, our hands-on activities focus on the cellular features in muscle fibers that contain multiple nuclei or multinucleated cells (Demonbreun et al., 2015; Sampath et al., 2018). This cellular feature of multinucleated cells is also called a syncytium (Figure 1). In our article, we provide middle school teachers with a step-by-step guide to engage middle school students in the process of muscle cell function and making predictions.

○ Step-By-Step Assembly of the Clay Velcro Origami Model of Forming a Syncytium

As shown in Figure 2, we provide a stepwise process to provide different textures to represent the molecular and cellular process of syncytia formation depicted using Velcro, Saran wrap, and clay. The clay represents the cell nucleus, while the Velcro illustrates the plasma membrane, and the Saran wrap illustrates the cytoplasm. Each component has a different texture for students. (panels A to F). Panel A, before cell fusion, each individual cell has its own DNA and plasma membrane. Panel B, once key molecular signals attach plasma membrane together, the cells form a one large continuous plasma membrane with multiple nuclei called a syncytium. Panel C, illustrates a step-by-step diagram in using Saran wrap and clay that symbolize the cytoplasm and nucleus, respectively (Figure 2, panel C). In order to construct the outer and inner layer of the plasma membrane, two Velcro strips are folded together (Figure 2, panels D to F).

In the next two sections of our article, we provide a step-by-step breakdown of relevant background for teachers to implement hands-on approaches to allow students to explore and make predictions on cell structure and function in the context of muscle

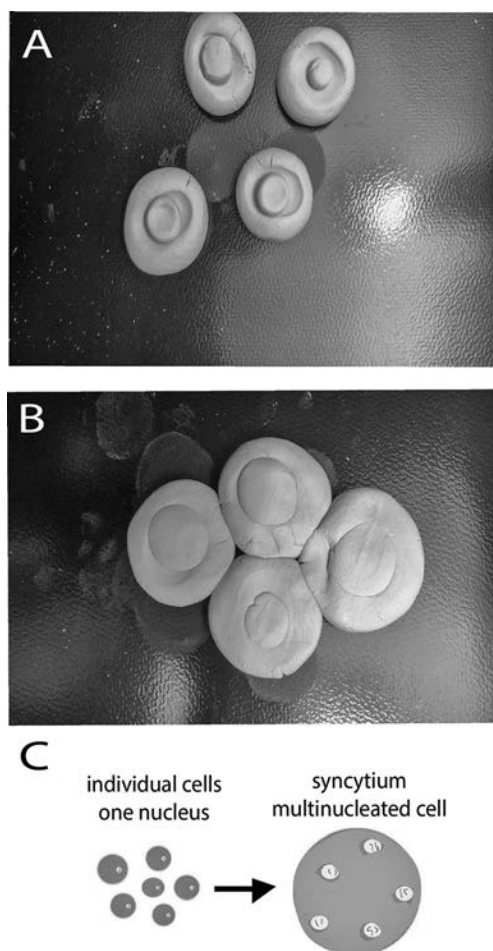


Figure 1. Overview of forming a syncytium.

Syncytia formation involves key molecular and cellular steps (panels A to C). Panel A, before cell fusion, each individual cell has its own DNA and plasma membrane. Panel B, once key molecular signals attach plasma membrane together, the cells form a one large continuous plasma membrane with multiple nuclei called a syncytium. Panel C, illustrates an overview of the cellular process of forming a syncytium. In blue is the cytoplasm and yellow indicates the nuclei in syncytium and the nucleus in each individual cell before cell fusion. A full-color version of this figure can be seen in the online version of this article.

Table 1. Linking Learning Objectives with NGSS on Cell Structure and Function

Next Generation Science Standards (NGSS) Middle School (MS) Life Science (LS)-1-2 From Molecules to Organisms: Structures and Processes	Learning Objectives	Hands-on Velcro/Clay Model Activities with Students
Develop and use a model to describe the function of a cell as a whole and ways the parts of cells contribute to the function.	Define a syncytium using hands-on model approaches. Apply the molecular and cellular process of syncytium in the context of muscle fiber formation.	Model the molecular and cellular changes at the plasma membrane during muscle fiber formation.
Science and Engineering Practices: Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progress to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.	Make a prediction if one of the signals in syncytium formation does not work, and describe its effects on cell function.	Use Velcro/Clay models to allow students to explore the cellular changes when muscle fibers are unable to fuse together to form a muscle fiber.

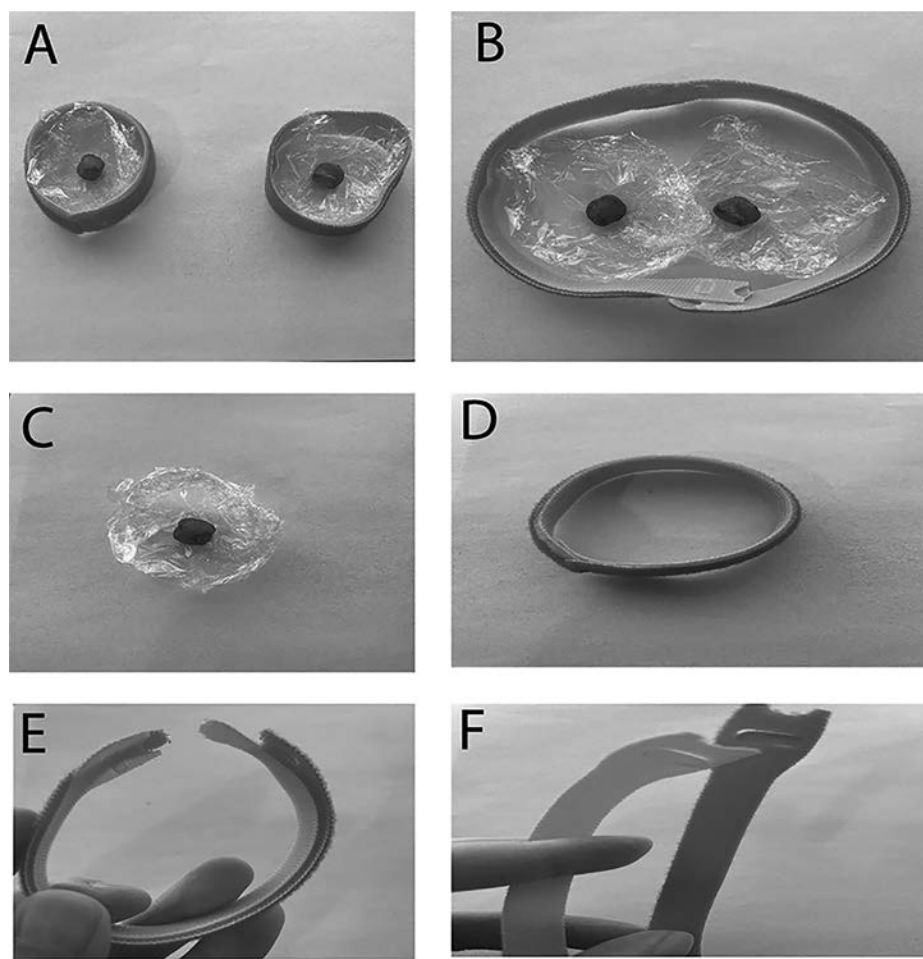


Figure 2. Velcro clay origami model on making a syncytium.

Syncytia formation depicted using Velcro, Saran wrap, and clay. The clay represents the cell nucleus, while the Velcro illustrates the plasma membrane, and the Saran wrap illustrates the cytoplasm. Each component has a different texture (panels A to C). Panel A, before cell fusion, each individual cell has its own DNA and plasma membrane. Panel B, once key molecular signals attach plasma membrane together, the cells form a one large continuous plasma membrane with multiple nuclei called a syncytium. Panel C, modeling cytoplasm as saran wrap and ball of clay as the nucleus. Panels D to F, double-sided Velcro views of the inner and outer plasma membrane used to model the cellular process of a syncytium.

Table 2. Glossary of Terms on Cell Fusion

Term	Description
cell fusion	Multiple cells with a single nucleus come together to form an enlarged cell with many nuclei, known as a syncytium. The nucleus is the innermost part of the cell that contains rich genetic material surrounded by a protective layer called the plasma membrane.
syncytium	A large multinucleated cell that is created by attaching two or more single cells together. Syncytia are surrounded by the plasma membrane that separates the inside from the outside of the cell, creating a protective barrier.
fusogen	Special sugar-coated proteins or glycoproteins that give direction to the cells and allow the plasma membrane from different cells to attach and connect to one another.

fiber formation and viral infections. As shared in Table 1, the class learning objectives are linked to the middle school life science MS-LS1-2 *From Molecules to Organisms: Structures and Processes* (NGSS, 2013). Furthermore, we have included Table 2 that shares a relevant glossary of terms that teachers may use to share with students.

Teaching Tips for Engaging Students in the Process of Using Hands-on Models of Muscle Fiber Formation

Before starting the hands-on activity model, teachers are invited to review several molecular and cellular feature. First, it will be helpful to verbally share a few sentences on the importance of forming

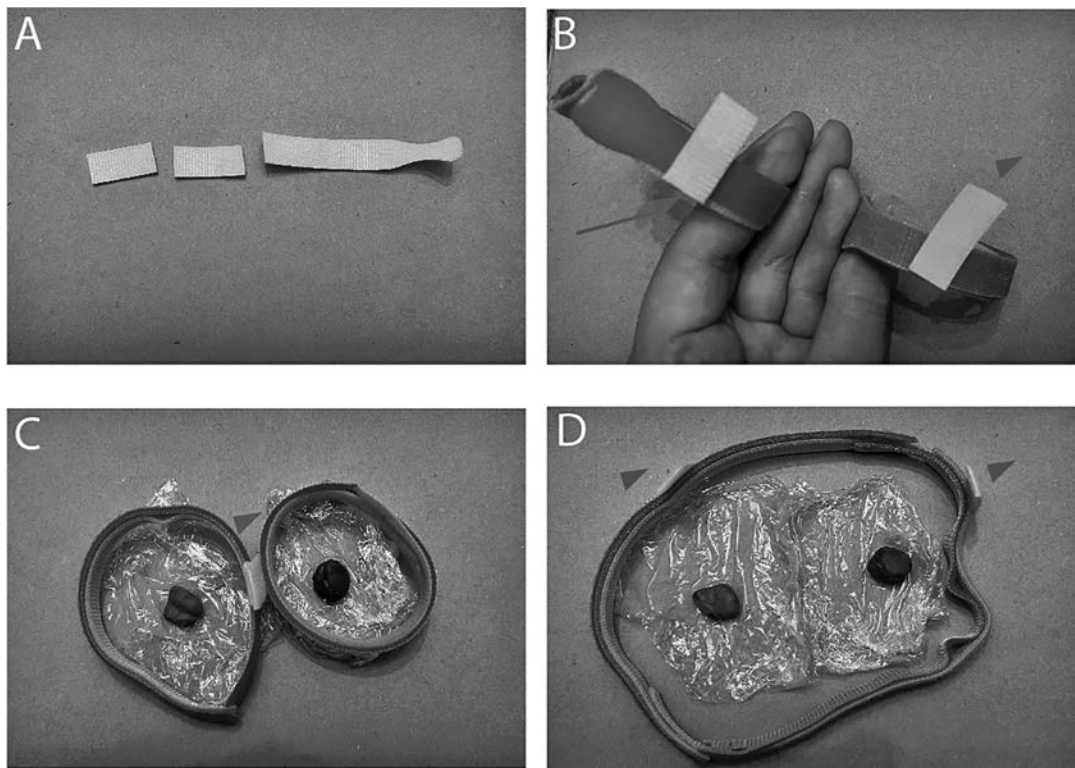


Figure 3. Velcro clay model of forming a syncytium in muscle fibers.

(A) To model the sugar-coated protein (or glycoprotein) fusogen that promotes cell fusion in muscle fiber cells, separated Velcro is used. (B) Magenta arrow shows the fusogen Velcro on one end of the plasma membrane in one cell, and other fusogen Velcro on the other plasma membrane with the magenta arrow point. (C) Magenta arrow point showing fusogen Velcro that links two plasma membranes from two muscle fiber cells. (D) Two magenta arrow points show fusogen after formation of muscle fiber cell syncytium.

a syncytium. It may be helpful to create an audio podcast and specifically describe that muscle fiber cells in our body have multiple nuclei that have special proteins (e.g., molecular brains called transcription factors) that act to form muscle cells. In Table 2, these individual early muscle cells use another set of special proteins called fusogens (Segev et al., 2018) that are sugar-coated proteins or glycoproteins that surround the length of the plasma membrane and allow each individual cell to fuse together to form a functional muscle fiber or myotube.

During the hands-on muscle fiber construction activity from Figure 2, prepare the clay, Saran wrap, and Velcro for each student and invite each student to collaborate in teams to create a muscle fiber or a cell that contains multiple nuclei called a syncytium. Teachers are encouraged to tell their students to save each model from activity one, as they will be helpful to return to in activity two when making predictions on whether muscle fibers do not fuse together.

While engaging students in construction of the Velcro clay model of syncytial formation, the following narrative can be included during the assembly process: Our human body is made up of over 37 trillion cells! Each cell is the body's building block for our heart and lungs to function. Within each cell, there are two special molecular parts. First, there is a special molecular Google map or a recipe book of information called the nucleus. Specific cell types in our bodies, such as lung epithelial cells contain only one nucleus. There are additional cells in our bodies, such as skeletal muscle cells, that contain multiple nuclei for our arms and legs to

move when we exercise. The second part is a special molecular Zip-Lock bag-like molecular device called the plasma membrane that surrounds the entire cell.

Once each student has created individual clay Velcro cells models of individual muscle fibers and another fused or a muscle fiber syncytium with multiple nuclei, mention to the class that along the outer surface of the plasma membrane contains special sugar-coated proteins called fusogens that act like molecular sticky glue that attaches the outer layer of the plasma membrane from two cells and then forms a continuous plasma membrane to form a functional muscle fiber cell (Figure 3).

Teaching Tips for Using Hands-on Models

Making a prediction using the clay Velcro origami model is connected to science and engineering practices in the middle school setting. As an extension from activity one, we return back to the muscle fiber cell. Have students bring their individual Velcro clay cell models and the syncytial cell with multiple nuclei and then ask what would happen if the individual Velcro pieces of the fusogen are not present—what would happen to the cell?—would it remain as an individual cell, or would it form one large cell with many nuclei (healthy muscle fiber cell)?

Have students share their prediction, and then begin to clarify the process that since the fusogen is missing, the individual muscle cells are not able to attach to one another and the cells cannot connect with one another and form a syncytium (Figure 4). It will also be helpful to share that if individual muscle cells do not

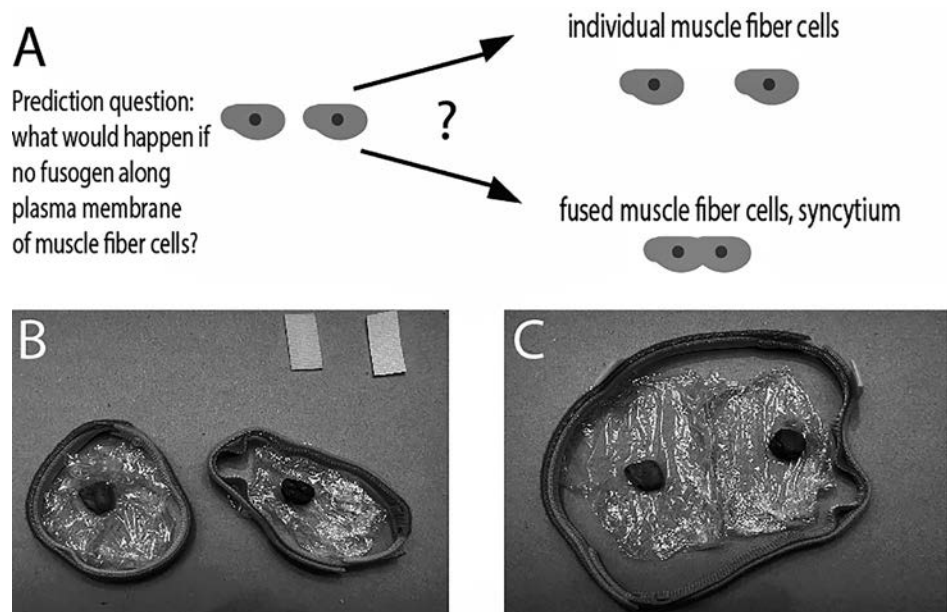


Figure 4. Using Velcro clay model for student to explore prediction on the process of syncytial formation in muscle fibers. (A) Diagram guide for teachers to guide students in making a prediction if one of the molecules called a fusogen is not present along plasma membrane of muscle fiber cells. (B) An example of model of fusogen (yellow Velcro strips) that are not attached to plasma membrane and two distinct muscle cells that are not fused. (C) An example of a fused muscle cell that has formed a syncytium.

form a syncytium, then the individual cells can cause muscle loss or muscle wasting such as in patients living with Duchenne muscular dystrophy (Demonbreun et al., 2015). The muscle loss or muscle wasting is caused by a cell death process called apoptosis.

In summary, our clay Velcro origami models of muscle fiber formation complements additional resources, including the raised paper graphics of biological process and cross-disciplinary themes in STEAM (Gardner, 1996; Harris et al., 2022; Indigenous STEAM, 2020). Furthermore, our presented hands-on model also provides a framework to encourage teachers to integrate NGSS learning outcomes with engineering and cross-cutting concepts. In addition, the interactive models may also be integrated with music in the classroom to promote an inclusive community of learners (Modell, 2018). Finally, our hands-on muscle cell activities may also be repurposed for science outreach settings for community-wide engagement.

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