ANIMAL SCIENCE (HS)

Ruminating on digestion

Focus question	How does the cow's multi-chambered stomach allow for breaking down cellulose-rich plant material?
Learning target	Students explain how the cow's multi-chambered stomach functions to break down cellulose-rich plant material. Students analyze how microbial symbiosis in the rumen supports the cow's digestive efficiency.
Vocabulary	Digestion chambers, ruminating, rumen, reticulum, omasum, abomasum

HS-LS1-2 From Molecules to Organisms: Structures and Processes
HS-LS2-3 Ecosystems: Interactions, Energy, and Dynamics

Performance expectation HS-LS1-2	**Classroom connection:** Students create a labeled diagram or flowchart to model the structure and function of the cow's four-chambered stomach, highlighting the specialized roles of the rumen, reticulum, omasum, and abomasum, demonstrating how the digestive system works as an organized system.
Performance expectation HS-LS1-3	**Classroom connection:** Students explain the role of microbes in breaking down cellulose and releasing energy for the cow.

Science and engineering practices

Developing and Using Models	**Classroom connection:** Students build and annotate models of the cow's stomach using diagrams or physical representations, illustrating the digestive process and interactions between chambers.
Constructing Explanations and Designing Solutions	**Classroom connection:** Students write explanations connecting microbial activity to energy cycling in the rumen, applying evidence from diagrams, video demonstrations, or class discussions.
Engaging in Argument from Evidence	**Classroom connection:** In small groups, students analyze the importance of ruminant digestion for nutrient cycling and sustainability, then present arguments based on evidence from their models and class materials.

Disciplinary core ideas

HS-LS1.A: Structure and Function	**Classroom connection:** Students explore how the specialized structure of each stomach chamber (rumen, reticulum, omasum, abomasum) supports its function, labeling and explaining in flow diagrams or group presentations.
HS-LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	**Classroom connection:** Students examine microbial fermentation in the rumen and explain how it demonstrates the cycling of matter (e.g., cellulose breakdown) and energy flow through the cow's digestive system.

Cross-cutting concepts

Systems and System Models	**Classroom connection:** Students view the cow's digestive system as an interacting system of subsystems, represented in diagrams and group discussions.
Energy and Matter	**Classroom connection:** Students explore the flow of energy and cycling of matter as plant cellulose is broken down by microbes in the rumen, analyzed in a group discussion and short writing assignment.
Structure and Function	**Classroom connection:** Students discuss and present how the anatomical specialization of each stomach chamber is adapted for its unique role in digestion, supported by examples from videos or 3D models.

Background

Cows and other ruminants (e.g., sheep, goats, and deer) have specialized digestive systems that extract nutrients from fibrous plant materials like grass and hay. Unlike monogastric animals such as humans, ruminants possess a four-chambered stomach designed to break down cellulose, a major component of plant cell walls, which is indigestible by most other species. This allows grazing animals to extract protein and other nutrients from grasses. See: `fda.gov/media/80784/download` for more information about the enzymes and mechanics of cow digestive systems.

By knowing how the ruminant digestive system works, livestock producers can better understand how to care for and feed ruminant animals. On average, cattle take from 25,000 to more than 40,000 'non-chewed' bites to eat forage while grazing each day. Cattle harvest forages during grazing by wrapping their tongues around the plants and then pulling to tear the forage for consumption. The roof of the ruminant mouth has a hard dental plate. Cows can use their tongues to wrap around plants and pull to tear the forage. The lower jaw has wide front teeth that work against this hard dental pad. These teeth crush and grind plant material during initial chewing and rumination. These teeth crush and grind plant material during initial chewing and rumination.

Saliva in ruminants acts as a buffering agent and provides a source of nitrogen for the microbial population in the rumen. The mouth and rumen/reticulum are connected by the esophagus. The esophagus moves food materials both ways, downward into the stomach and upwards for rumination or further "chewing of the cud." The mouth and rumen/reticulum are connected by the esophagus. The esophagus moves food materials both ways, downward into the stomach and upwards for rumination or further "chewing of the cud."

Cows typically spend more than one-third of their time eating, one-third of their time ruminating/regurgitating and/or cud chewing, and slightly less than one-third of their time resting.

In this lesson, students are asked to build a model of the four chambers of a ruminant's stomach and show what happens within each chamber. Use the following information to guide students:

- The **rumen** ferments cellulose with microbial help. It receives food or cud from the esophagus, absorbs digested nutrients with the aid of bacteria and other microbes, and passes it to the reticulum.
- The **reticulum** traps larger particles for re-chewing (cud formation). It has a honeycomb-like structure and receives food from the rumen and passes it to the omasum.
- The **omasum** absorbs water and some nutrients. It has layers/folds of tissue, similar to pages in a book, which increases surface area leading to greater water absorption.
- The **abomasum** (true stomach) uses acid and enzymes for final digestion.

Highlight how the interaction between the chambers and their structures enables efficient digestion in ruminants.
Use a blender to represent food grinding as seen in the mouth (chewing cud). This would happen in rumen and reticulum containers.

Prior knowledge

Students need a basic understanding of the digestive process: food is broken down in the stomach and the body uses that fuel to grow, repair, and maintain survival. The difference between a monogastric and a ruminant system allows cellulose as a structural component in plant cell walls to be broken down with microbial help. A basic knowledge of fermentation and microorganisms breaking down matter is helpful.

Suggested timing

2–3 days, depending on class length (one day of research, one day to build, one day to test and collect stomach data)

Materials

- Clear plastic containers to represent the four stomach chambers
- Additional materials to represent the physical characteristics of the chambers (honeycomb silicone trays, newspaper or pieces of dusters, microfiber towel pieces, etc.)
- Food items: hay or straw (dry, cut grass or leaves), green leafy vegetables, bread
- Plastic bags
- Water, vinegar, and baking soda (to simulate digestive fluids and enzymes)
- Cellulase enzyme, if available
- Blender or food processor or chopping items
- Paper and markers for labeling
- Gloves and aprons for students
- Large poster paper for creating a visual digestion process

Teacher preparation

1. Provide materials for student research (i.e. animal anatomy textbook and/or websites where students can find information) and paper/whiteboards for creating a diagram of digestion (Day 1). This handout could be helpful: `fda.gov/media/80784/download`.
2. Gather materials for students to create their chamber model. Students may work in groups of 2 or 3.

Procedure

Day 1: Research

Students research and create a diagram or digital model of the cow's digestive system, focusing on each chamber's unique function and the microbial activity involved.

Use a guided research document that asks students to find information about their assigned chamber:

1. What is the structure?
2. What are the functions?
3. What enzymes or microbes are found there?
4. What should food look like when it leaves this chanber to enter the next?

Day 2: Lab

1. Divide students into pairs and assign each group one of the four chambers.
2. Have students create a container that would resemble the physical structure of the chamber and mimic the process that takes place in each of the chambers.
    - **Rumen:** Hay and water are mixed with "microbial enzymes" (a diluted vinegar solution or cellulase).
    - **Reticulum:** The leftover rumen mix is coarsely mashed to simulate mechanical breakdown. This mixture should be dense, as this is where things get dumped, barely chewed or digested.
    - **Omasum:** The folds of the omasum will absorb water from partially digested materials.
    - **Abomasum:** Add lemon juice, vinegar, or a weak HCl acid to simulate stomach acids; use pH strips to measure acidity.
3. Ask students to collaborate with students from other groups to determine the relationships between each, making observations or drawing arrows on the diagrams they created on day 1 to follow the path of feed within the animal.
4. Have them hypothesize and then record pH levels, structural changes in food, and overall observations of breakdown across chambers.
5. Have each group prepare a detailed report or presentation covering the following:
    - Analysis of the digestive processes and biochemical changes in each chamber.
    - Explanation of how the cow's multi-chambered stomach is adapted for breaking down cellulose-rich plant material.
    - Discuss the role of each chamber in nutrient extraction and overall health impacts.
6. Have students present their findings, using diagrams, pH data, and photos taken throughout the process to explain each chamber's role. Encourage students to draw connections between ruminant digestion and how it differs from monogastric systems (e.g., human digestion).

Day 3

Have students finalize a diagram or digital model of the cow's digestive system, focusing on each chamber's unique structure, function, and the microbial activity involved.

Student handout

Reflection

1. How do the different chambers of the cow's stomach work together to ensure efficient digestion?

Possible answers: Each chamber has a specialized function. The rumen absorbs nutrients that are immediately available, while the reticulum is a holding tank for the large amount of feed/forage that the cow eats.

2. What happens to the molecules produced during digestion?

Possible answers: They are absorbed in different parts of the digestive system, some in the stomach, but many in the small intestines.

3. How are they used by the cow's body?

Possible answers: The molecules provide energy for the cows daily activities, are rearranged into necessary building blocks for milk formation, and are used to provide energy for the lactating cow in order to produce milk.

4. How does energy flow from the cow's food to its cells?

Possible answers: By being broken down through the action of microbes with the help of enzymes, absorbed by the small intestines, used by the cells for energy and reassembled into milk and other necessary bodily functions.

Differentiation

Other ways to connect with students with various needs:

- **Local community:** If there are nearby farms or farmers' markets that carry the commodities that you plan to use for the lesson, reach out to see if a farmer would be willing to come to your class to speak on the topic of all the uses for their commodity and how they cultivate the product. If there are no farms in your local area, reach out to your local extension office to see if an agent or a farmer would virtually visit your classroom.
  Where did my milk come from? **whereismymilkfrom.com**
- **Students with special needs (language/reading/auditory/visual):** Students with special needs will be placed in lab groups to work collaboratively with other students. If they struggle with reading, the group will work together. A stronger reader will be made the director of the group to read the lab sheet aloud to the rest of the group. After this, the group will discuss how to proceed or what answers they will then put down on the paper. ESL students may need to utilize their translation devices with the group to fully communicate with their peers.
- **Extra support:**
  - Science learning hub: **sciencelearn.org.nz/image_maps/104-ruminant-digestion**
  - Horizon Veterinary clinic: **horizonvetbrighton.com/site/blog/2022/06/15/understanding-the-ruminant-digestive-system**
  - University of Minnesota extension: **extension.umn.edu/dairy-nutrition/ruminant-digestive-system#stomach-compartments-1000460**
- **Extensions:**
  - Compare digestive systems: Students research and compare the cow's digestive system with those of other animals, such as monogastric animals (humans, pigs) or other herbivores (horses, rabbits). They may create a Venn diagram or chart highlighting similarities and differences. *Guiding question:* How does the structure of a digestive system align with an animal's diet?
  - Design a digestive system for an alien: Based on their understanding of digestion, students create a model of a digestive system for a hypothetical alien species that consumes a unique diet (e.g., rocks, methane). *Guiding question:* How would you design a digestive system to process non-organic material?

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Developing and Using Models	The model is incomplete or inaccurate, with little effort to show the digestive system or its interactions.	The model is clear and functional, showing the structure of the digestive system with minor inaccuracies or omissions.	The model is highly accurate, and detailed, and effectively demonstrates the structure and function of all components.
Constructing Explanations	Explanation is unclear or lacks scientific reasoning, with minimal connection to evidence or concepts.	The explanation is accurate but may lack depth, with some use of evidence to connect concepts.	Explanation is thorough, well-supported by evidence, and demonstrates strong scientific reasoning.
Analyzing and Interpreting Data	Struggles to use or interpret data, with limited connection to how it informs understanding of digestion.	Interprets data accurately but with limited depth or application to digestion and microbial activity.	Analyzes data deeply, integrating insights into a cohesive understanding of digestion and microbial roles.
Engaging in Argument from Evidence	Limited effort to use evidence to support claims, with weak or unclear connections to digestion.	Uses evidence to support claims, though connections may not always be logical or fully developed.	Skillfully uses evidence to construct logical, well-supported arguments connected to digestion concepts.
Applying Crosscutting Concepts	Little to no understanding of structure-function relationships or systems models in the digestive system.	Demonstrates some understanding of structure-function and systems models, with minor gaps or inconsistencies.	Demonstrates strong understanding of structure-function and systems models, with clear and logical connections.

Rubric for self-assessment

Skill	Yes	No	Unsure
I can create a detailed and accurate model of the cow's digestive system that shows the process and all components.			
I can give a detailed explanation for how the structure of the cow's stomach impacts the functionality, using strong evidence.			
I can analyze data effectively and use it to explain and support my ideas with confidence.			
I can make a strong claim and use evidence effectively to support my argument.			
I can clearly explain the connections between the structure of the stomach and the function of digestion, with strong reasoning.			