Module 1 – Foundations of Sustainable Agri-Food Systems & Circular Economy

Differentiated Content Lecture & Speaker Notes

Systems Thinking & Nature as the Ultimate Circular Model

Differentiated Content

Option 1, broader. This lecture introduces systems thinking as a foundational mindset for understanding sustainability, food systems, and waste. It connects to NGSS concepts such as cause-and-effect relationships, system dynamics, and feedback loops in biological and human systems.

Option 2, more specific. This lecture deepens the understanding of systems theory and ecological modeling. NGSS-aligned topics include:

- System feedback mechanisms (positive and negative)
- Ecosystem modeling and energy flow
- Material cycling and stability of biological systems
- Human impacts and bio-inspired system design

Option 1: What Is Systems Thinking? How Do We Already Use It?

Overview of Metabolic Modeling

Systems thinking means understanding how parts of a system interact — not just individually, but collectively. In this lecture, students learn how to recognize systems around them and reflect on how their actions have ripple effects. This lays the groundwork for analyzing food systems and sustainability challenges.

Key Concepts:

- **What is Systems Thinking?**
  - A way of seeing the whole picture — how the parts of a system connect, affect each other, and change over time
  - Focus: Looks at relationships, not just parts; helps us understand ripple effects of our actions
  - Goal: See the connections so we can make changes that last, without causing new problems
  - Example: Your lunch is part of a food system with farmers, transporters, water, soil, energy, and waste
- **Key Concepts of Systems Thinking:**
  - Feedback Loops – Cycles where results affect what happens next
  - System Archetypes – Common patterns that systems follow
  - Leverage Points – Small changes that can make a big difference
  - Unintended Consequences – Surprises caused by hidden connections or delays
  - Example: Your lunch is part of a food system that involves farmers, transporters, water, soil, energy, and waste
- **From Linear to Circular:**
  - Place Your Dot: Mark where your lunch item fits on the diagram
  - Check for Shortfall or Overshoot:
    - Inside hole? → Not enough benefit (nutrition, fairness)
    - Outside ring? → Too much harm (pollution, resource use).
  - Discuss: How could we move your dot into the “safe and just space”?
- **Nature as the Ultimate Circular Model:**
  - Key Idea: In nature, nothing is wasted; every output becomes an input for something else
  - Why It Matters: Nature runs on closed loops that keep ecosystems healthy, balanced, and resilient. We can copy these patterns to design better human systems, including food production
  - Takeaway: If nature can use everything, so can we — through a circular economy

Doughnut Mapping Activity (Classroom Exercise)
Introduction:

- Students place a dot representing their lunch item on a blank doughnut diagram:
- Inside the hole = social shortfall (e.g., not enough nutrition, poor access)
- Outside the ring = ecological overshoot (e.g., too many emissions, plastic waste)
  Prompt:
  - “Does your burger contribute to greenhouse gas emissions?”
  - “Does your salad fall short in nutrients or food justice?”

  Discussion (2–3 min):
  - Show how closing loops (e.g., composting food scraps) can move points back into the “safe and just space” of the doughnut.
  - Link this to the circular economy idea that resources should cycle — not end in a landfill.

Real-World Applications
Use examples of nature’s circular systems, such as:

- Forest: Fallen leaves → decomposers → nutrients → plant roots → new growth
- Mycelium: Underground fungi share water & nutrients between plants
- Beehive: Bees pollinate → more plants grow → more nectar → more bees

Delve into a case study on creating new products from coffee waste:

- A city café network collects used coffee grounds instead of throwing them away. The grounds are sent to a local facility where they are dried and processed into two products:
  - Mushroom-growing kits for schools and restaurants
  - Bioplastic pellets used to make reusable coffee cups
- Systems Thinking Link:
  - Feedback Loops: Coffee grounds → mushrooms & cups → reduces waste → lowers demand for new plastic
  - Leverage Point: One small change in waste handling transforms the whole supply chain
  - Result: Cuts landfill waste, reduces plastic pollution, creates new jobs, and engages the community.

Then compare with broken human loops in food systems (human-designed circular model ‘mimicking’ nature’s circular loop):

- Contrast with nature: Many human systems are “open” loops where resources are lost instead of reused
- Examples:
  - Food waste → landfill methane instead of compost
  - Single-use packaging → plastic pollution instead of reuse
  - Nutrients from food scraps → lost instead of returned to soil
- Prompt: “Looking at these broken loops, which one do you think would be the easiest to fix in our school, and how could we do it?”

NGSS Integration
Relevant NGSS Science Topics:

- **Cause and effect relationships** (Crosscutting Concept)
- **Energy flow through ecosystems** (HS-LS2-3)
- **Cycling of matter in living systems** (HS-LS2-4)
- **Influence of engineering on ecosystems** (ESS3.C)

Ask Students:

- If you were to “redesign” your school cafeteria as a circular system, what changes would you make to close loops and reduce waste?
- Which of these changes are inspired by natural systems?
- How could feedback loops be used to keep our cafeteria system running more efficiently over time?
- How could student behavior be part of a reinforcing loop for waste reduction?

Option 2: Technical Lecture on Root Microbiome Engineering via Metabolic Modeling

Introduction

This lesson invites students to explore how nature models the circular economy through systems thinking. By comparing natural cycles (like a forest) with man-made systems (like a school cafeteria), students begin to understand the gaps, breaks, and opportunities for design in our food system. Nature becomes the teacher, offering real solutions for sustainability.

System Inputs and Outputs

Component	Input	Output
Ecosystem Model	Energy sources, nutrient stocks, species roles	Predicted energy flow diagrams, nutrient cycling maps
Human-Managed System Model	Resource inputs, waste outputs, loop closures	Stability metrics, waste-reduction potential, design adjustments

Modeling Interactions

- Positive feedback: Processes that amplify change (e.g., unchecked soil erosion increasing nutrient loss).
- Negative feedback: Processes that counterbalance change (e.g., predator-prey dynamics stabilizing populations).
- Energy flow mapping: Modeling how sunlight, biomass, and heat transfer through trophic levels.
- Material cycling: Tracking nutrient movement from production → consumption → waste → regeneration.

Circular Design Benefits

- Identifies broken loops in human-managed systems (e.g., nutrient leakage to waterways).
- Highlights opportunities to mimic nature’s self-reinforcing cycles (e.g., composting, water reuse).
- Supports bio-inspired design for resource efficiency and long-term stability.

Challenges Addressed

- Overreliance on linear resource flows (Take → Make → Waste).
- Ecological overshoot from exceeding planetary boundaries.
- Loss of resilience when feedback loops are disrupted.

Ask Students:
If you modeled your school's cafeteria as an ecosystem, which feedback loops would you find? Where are loops broken, and how could natural circularity repair them?

NGSS Integration and Student Reflection
Relevant NGSS Science Topics:

- **Interdependent relationships in ecosystems** (MS-LS2-2)
- **Human impacts on Earth systems** (ESS3.C)
- **Using mathematics and computational thinking** (SEP-5)
- **Engineering design and optimization** (ETS1.A/B)

Encourage teams to sketch a loop diagram showing both a natural nutrient cycle (forest or ocean) and a human-managed one (cafeteria, farm). Annotate where positive and negative feedback occur, and mark where loop closures would move the system closer to the "safe zone" in the doughnut model.