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Foundations of Cognitive Science

Design Document: Matter, the Food Chain, and Decomposition Lesson

Introduction

Nature recycles. Decomposition is the process of the breakdown of complex organic matter into inorganic substances, like carbon dioxide, water, and nutrients. Since decomposition is essential for recycling the finite matter that occupies physical space in the biosphere, teaching kids this process is necessary. So, our team has decided through multimedia with cognitive sciences, to design an interactive, computer-based lesson for kids to engage with essential science concepts.

The multimedia lesson we designed is intended for an audience of 5th-7th grade science students. Our lesson is grounded in learning goals within the Next Generation Science Standards (NGSS), standard 5-LS2: Ecosystems: Interactions, Energy, and Dynamics for 5th grade science. NGSS is widely used in U.S. public schools. Our unit is based on knowledge in standards listed in Figure 1.

Figure 1

PS3.D: Energy in Chemical Processes and Everyday Life	The energy released [from] food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (5-PS3-1)
LS2.A: Interdependent Relationships in Ecosystems	The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. (5-LS2-1)
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, and water, from the environment, and release waste matter (gas, liquid, or solid) back into the environment. (5-LS2-1)
Crosscutting concept: **Energy and Matter**	Matter is transported into, out of, and within systems. (5-LS1-1) Energy can be transferred in various ways and between objects. (5-PS3-1)

National Research Council, 2012 https://www.nextgenscience.org/pe/5-ls2-1-ecosystems-interactions-energy-and-dynamics

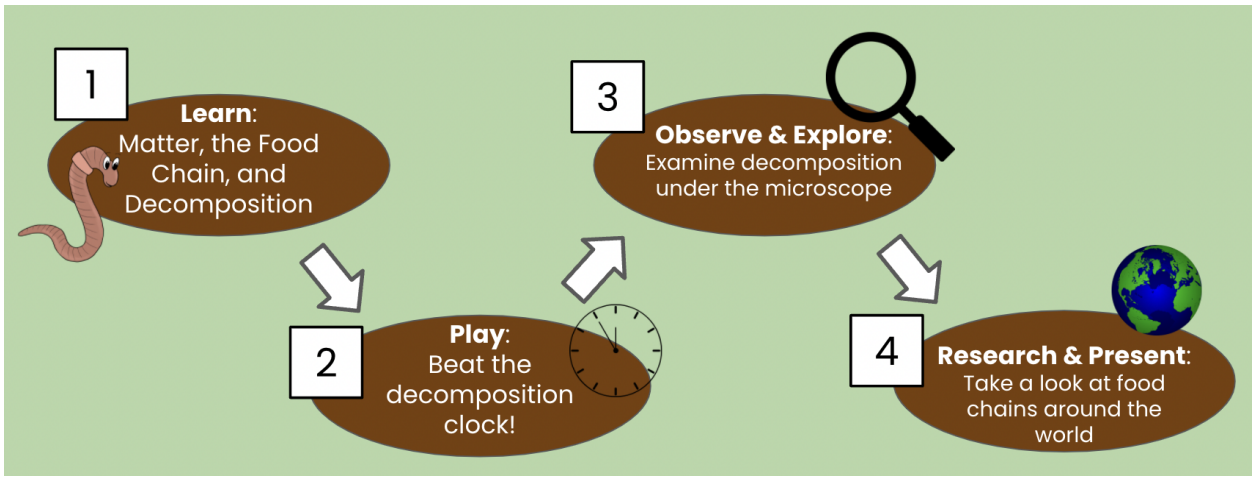
Our lesson is designed to introduce the topic, allow students to explore on their own through a game, an interactive map, and an interactive microscope, reflect on what they've learned, and

finally conduct self-guided learning with a team related to the topic. An abridged sequence for our lesson is as follows:

1. (Learn) Introduction: Matter, the Food Chain, and Decomposition
2. (Play) Beat the Decomposition Clock
3. (Observe & Explore) Under the Scope
    a. Decomposing leaf (open as a PowerPoint, do not view in Google Slides)
    b. Decomposing badger
4. (Research and Present) Food Chains Across Ecosystems

To see the entirety of the lesson plan, please see Appendix A.

Figure 2



Cognitive Challenges & Probed Knowledge

Because this lesson is grounded in the NGSS framework, we assumed that students have been previously taught within this framework. Thus, we assume that they have prior knowledge of terms like *organism* and *ecosystem,* which are outlined in previous standards. This could pose challenges to students who don't recall the information, were taught insufficiently, or were not taught within the NGSS curriculum, because these schemas need to be built upon. Students also need to have very basic research and presentation skills.

Additionally, as this is a primarily self-guided module with educator support, students would need motivation to engage with and complete the lesson. In e-learning, engagement is often measured by a combination of behavioral and psychological actions (Clark & Mayer, 2016). While behavioral engagement will be measurable (educators can see when students are clicking, drag-and-dropping, and producing text), psychological engagement will be more difficult to monitor as it involves study and metacognitive skills that young learners are still developing.

As a result of these different cognitive challenges, probed knowledge will be twofold. Students will build their schemas in environmental sciences, such as identifying and categorizing particular organisms as producers, consumers, and decomposers. Students will also develop metacognitively by procedurally reflecting on the content in order to develop and present food chains from around the world to their peers.

Learning Environment

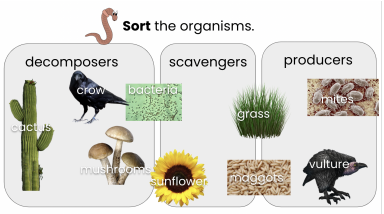
This lesson is designed for a 5th grade science classroom, and can be conducted by individual students in a computer lab, with the module accessible via web. This lesson could also be used in a virtual school environment. Students collaborate and present in person or via breakout rooms on Zoom. This lesson assumes that there is a teacher present in the room or accessible to facilitate responses to prompts and collaborative group work.

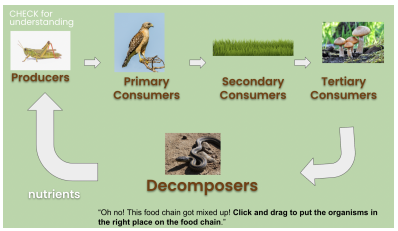
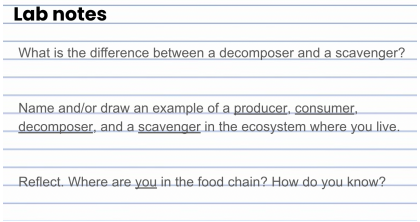
Our Design & Cognitive Theory

(Learn) *Introduction: Matter, the Food Chain, and Decomposition*

First, the introduction begins with an advanced organizer (Figure 2) to influence the learner's encoding process, and to help orient the learner within the lesson (Martinez, 2010 and Mayer, 1979). The verbs *learn, play, observe, explore, research, present* give the learner the sense that they will be active learners, and are in alignment with the revised Bloom's taxonomy. The learning sequence shifts from basic remembering and understanding, to applying the learner's own experience to their understanding, to creating a presentation, tapping into the factual, conceptual, and metacognitive dimensions throughout the lesson (Anderson & Krathwohl, 2001).

Figure 3

Dimension (Anderson & Krathwohl, 2001)	Activity
Factual dimension	 The learner shows they are familiar with the rules of the discipline.

Conceptual dimension	 The learner must relate organisms together within a larger structure.
Metacognitive dimension	 The learner must reflect on *why they know* where they are within the food chain.

Based on Mayer's Cognitive Theory of Multimedia Learning, our goals while designing this lesson were to reduce extraneous load, to amplify germane load, and to encourage learning through social cues (2014).

The strengths of the introductory module in relation to these three goals are reducing extraneous load through the signaling principle, amplifying germane load through the pre-training principle, and encouraging learning via social cues through the personalization principle.

The introductory lesson uses the signaling principle to identify the most important visual elements on the screen so that the learner can identify it more easily (Mayer & Fiorella, 2014). As you can see in Figure 4, the important learning elements are circled, thus signaled.

Figure 4

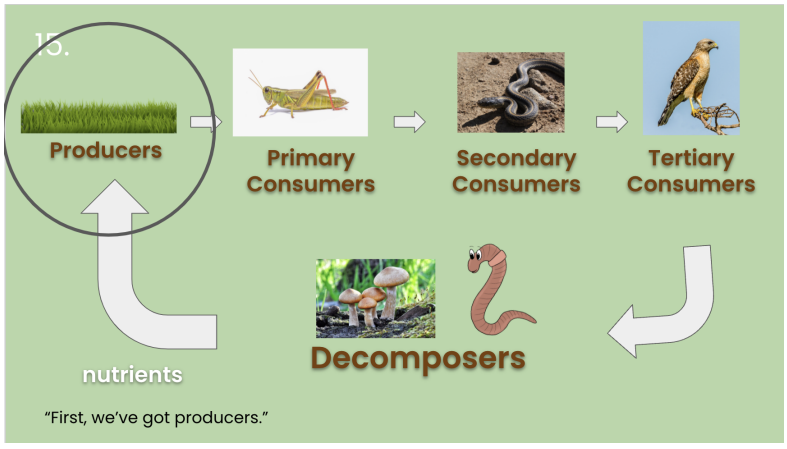


Figure 5 demonstrates the pre-training principle, a list of the most important vocabulary terms described in the lesson. This chart makes use of the idea that "people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts" (Mayer & Pilegard, 2014, p. 317).

Figure 5

Matter	Anything that has weight and takes up space.
Food Chain	The order in which living things depend on each other for food.
Producer	Organisms that produce their own food (plants).
Consumer	Organisms that eat plants or animals for food.
Decomposer	Organisms that break down dead organisms.

Figure 6 depicts Composta D. Worm, the avatar that guides the learner throughout the learning process. Composta speaks in a very casual, relatable way, thus encouraging learners (especially young learners, in the case of this lesson) to process complex information more deeply (Mayer & Pilegard, 2014). The anthropomorphic worm we designed, as well as its home and personality, helps learners connect to the content. A worm is a decomposer, so its form reinforces the main concept of the lesson.

Figure 6

(Observe & Explore) Under the Scope (Pt. 1, Leaf; Pt. 2, Badger)

Building from the introduction, learners follow Composta D. Worm as he continues to guide them on their journey. In the "Observe & Explore" section of the lesson module, learners are

invited to study decomposition and its associated organisms through an interactive microscope. Separated into two main parts (leaf and badger), our design makes use of the segmenting principle by: (1) allowing students control over their learning direction and (2) dividing key concepts into small chunks. As depicted in Figure 7, the "leaf" option looks at the objects being decomposed and their timelines, whereas the "badger" option examines each decomposer's role in the decomposition process. Additionally, Figure 8 showcases further segmented choice, as the learner can click where on the leaf (as indicated by the small red circles) that they would like to examine more closely and learn from.

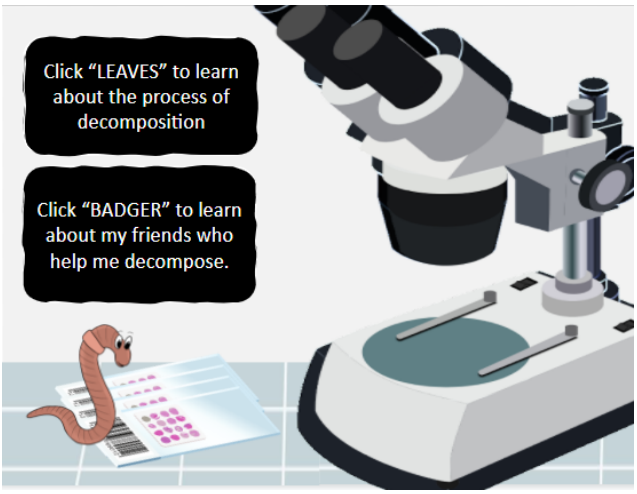


Figure 7
The two directions (*Click "Leaves" to…* & *Click "BADGER" to…*) fade away into clickable buttons that take the learner to their intended segmented course of learning.

Figure 8

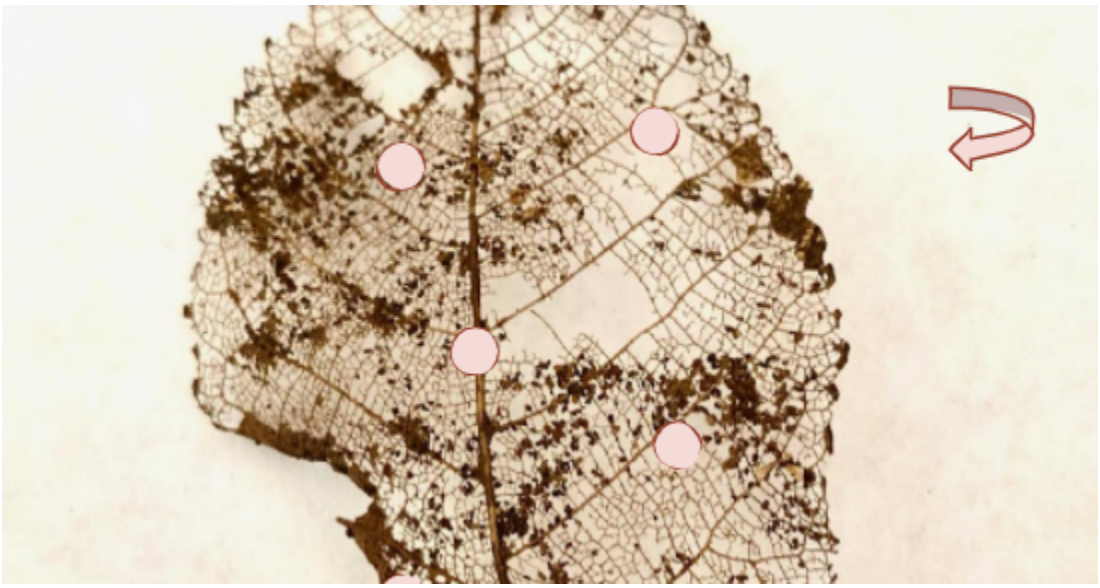
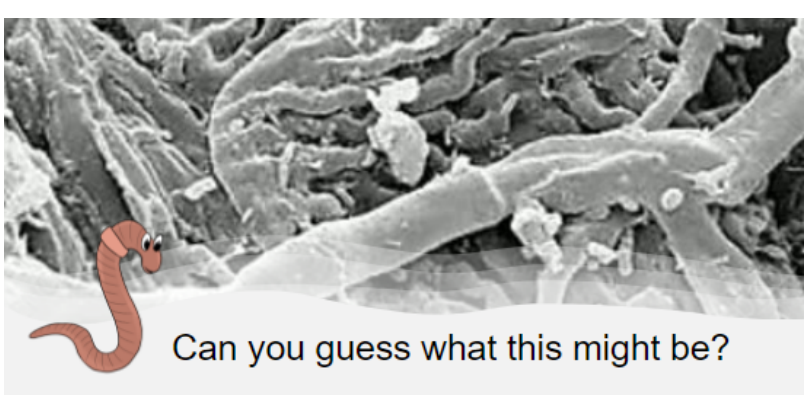


Figure 9 demonstrates our design's use of the image principle, which argues for animations and visuals that help reinforce the audio voiceover, rather than a talking head of our narrator. This design ensures that learners would not need to dedicate cognitive effort to "imagining" the

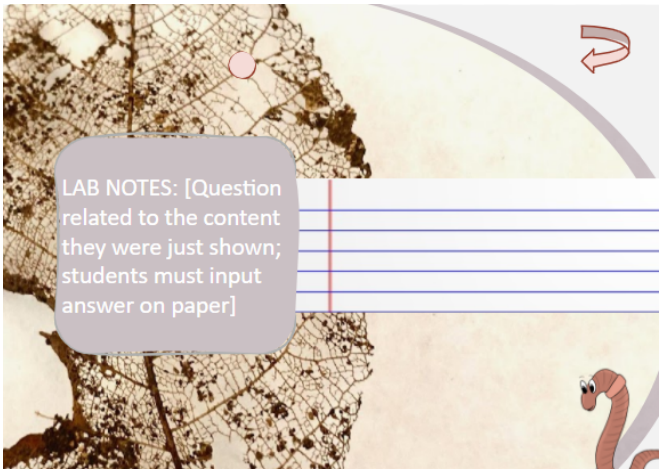
content being presented (avoiding heavy representational holding). Instead, learners focus on the content itself. Additionally, Composta D. Worm utilizes I/You pronouns, polite phrases and expressions to build a social presence that encourages the cooperation principle. He makes comments such as “Let’s…”, “Can you guess…?” and “Are you curious about…? I can help!” that bring the learner into an implicit, educational agreement.

Figure 9



Finally, our Under the Scope game aims to also help build students’ metacognitive abilities through a series of “LAB NOTES” that pop-up and encourage the learners to reflect on what it is they are learning and encoding into their schemas. These questions range in topic, from reflecting on the immediate portion of the leaf or badger just studied, to relating the information directly to the advanced organizer shown in the introduction’s pre-training. This is seen in Figure 10 below.

Figure 10



(Play) *Beat the Decomposition Clock*

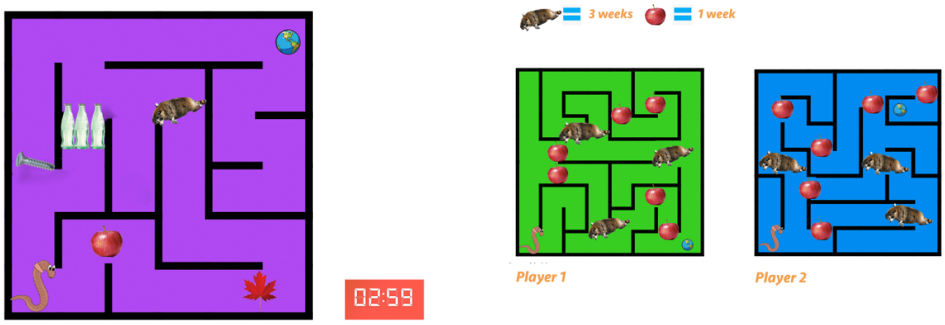
Our game's design focuses on enhancing the learning experience while still utilizing entertainment to support learner engagement. Since our target audience is 5th-grade students, during the design procedure, we aim to improve their attention and motivation when they play the game, meanwhile, optimizing the game's impact on their learning.

Cognitive load theory (CLT) has established a sound theoretical foundation to connect cognitive research on human learning with instructional design and development (van Mer-riënboer, Clark, & de Croock, 2002). Good instructional design's purpose is to reduce the ineffective cognitive load, and through reducing the extraneous cognitive load to improve the learner's cognitive information processing (Khalil, Paas, Johnson, & Payer, 2005a, 2005b; Mayer & Moreno, 2003). So, to reduce the students' extraneous cognitive load, we have decided to design the following aspects in our games.

1. Avoid Visual Clutter

No matter what kind of design, the ultimate goal is that keeping it simple. In our games, the interaction page only with all essential information. With the colorful maze map and different objectives icon, it is easy for the learner to play.

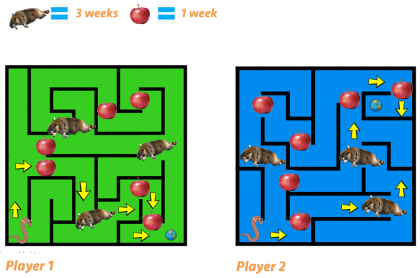
Figure 11



2. Provide Short-Term Memory Support

To reduce the cognitive load, we support the user by displaying information which they would otherwise have to store in their short-term memory, for example, the decomposing time of different organisms. In this way, the players can have more attention to the game itself.

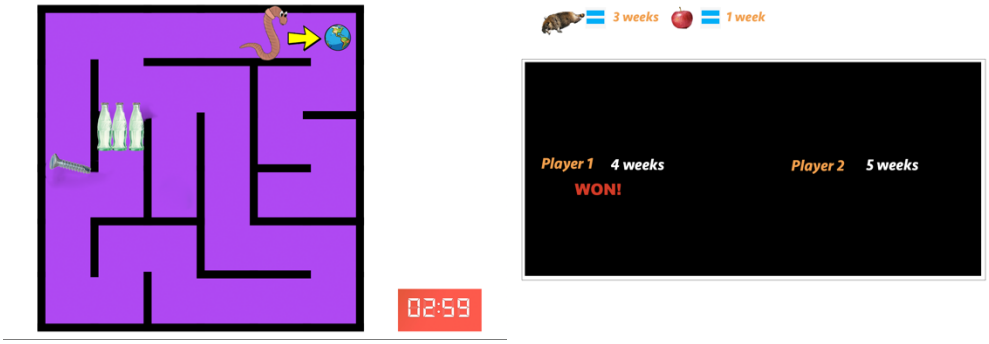
Figure 12



3. Add Competence in the Game

In Game One, we designed a limited time for players. They have to finish the game level within a certain time. In Game Two, we set it into a duo game, which needs more sense of progression to win. These competition elements spur the players' intrinsic motivation.

Figure 13



These two instructional designed games provide another perspective of multimedia learning. Through playing these games, besides the learners can have a deeper perception of decomposition, the games can boost their interests in learning as well.

(Research & Present) Food Chains Across Ecosystems

Students will be divided into groups to research an assigned ecosystem's food chain and present to the class. This element of our lesson is to encourage collaboration and students' individual presentation skills. Students will pull from their prior knowledge, as well as the new knowledge they gained through our module to create their own visual representation of food chains in different ecosystems.

The slides that our module provides are completely editable, and students will ultimately make the final decisions on all visuals, including organization and choice of image. As a result, the way we've designed these slides is to be a skeleton of the information they would need, and serve as a scaffold. This part of our lesson allows students to visually represent the schemas that they formed during our lesson. Throughout our module, we showed students graphic representations of food chains, so they will be able to use our visual models as a scaffold for their own slide. Giving students the opportunity to research on their own, create a visual model of a food chain, and present it to the class serves as a tangible assessment of our module as a whole. For students who need extra support in where to begin research, an outside website will be provided. This website uses spatial contiguity to associate key terms with relevant visuals, and provides a research scaffold. Educators can use this part of the lesson to provide feedback, and allow students to reflect on what they have learned.

Combining Principles of Multimedia Design & Learning Theory

Through the theories and rationale explained above, this lesson module aims to teach 5th graders standards of the science curriculum through interactive, engaging digital media and collaborative learning. Hands-on learning in science education is often a necessary yet out-of-reach component for many elementary and middle-school classrooms across the globe. While certain topics lend themselves to ease of accessibility, others include such particular materials that to recreate authentic lab-work is near impossible. However this can be mitigated with appropriate multimedia tools that not only connect students with faraway environments, but also build excitement for the learning material.

References

Anderson, L.W. & Krathwohl, D.R. (2001). *A Taxonomy of learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Addison Wesley Longman, Inc.

Clark, R. C., & Mayer, R. E. (Eds.). (2016). Engagement in e‐learning. *In e‐Learning and the Science of Instruction* (pp. 219–235). Hoboken, NJ: John Wiley & Sons.

Khalil, M. K., Paas, F., Johnson, T. E., & Payer, A. F. (2005a). Interactive and dynamic visualizations in teaching and learning of anatomy: A cognitive load perspectives. *The Anatomical Record Part B: New Anatomist*, 286B, 8-14.

Khalil, M. K., Paas, F., Johnson, T. E., & Payer, A. F. (2005b). Design of interactive and dynamic anatomical visualizations: The implication of cognitive load theory. *The Anatomical Record Part B: New Anatomist*, 286B, 15-20.

Mayer, R.E.(1979). Can advance organizers influence meaningful learning? *Review of educational research. Vol. 49* (2). p. 371-383. doi: 10.3102

Martinez, M. E. (2010). Theories of knowledge. *In Learning and Cognition: The Design of the Mind* (pp. 77–84). Boston: Merrill.

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 43–71). Cambridge: Cambridge University Press.

Mayer, R. E., & Fiorella, L. (2014). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learnin*g (2nd ed., pp. 279–315). Cambridge: Cambridge University Press.

Mayer, R. E., & Pilegard, C. (2014). Principles for managing essential processing in multimedia learning: Segmenting, pre-training, and modality principles. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 316–344). Cambridge: Cambridge University Press.

Mayer, R. E., & Pilegard, C. (2014). Principles Based on Social Cues in Multimedia Learning: Personalization, Voice, Image, and Embodiment Principles . In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 316–344). Cambridge: Cambridge University Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.https://doi.org/10.17226/13165.

van Merriënboer, J. J. G., Clark, R. E., & de Croock, M. B. M. (2002). Blueprints for complex learn-ing: The 4C/ID-model. Educational Technology Research and Development, 50(1), 39-64.

Appendix A

Matter, the Food Chain, and Decomposition

Topic: Environmental Science/Biology
Grade: 5th* - 7th Grade
*target grade

Standards Alignment

PS3.D: Energy in Chemical Processes and Everyday Life	The energy released [from] food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (5-PS3-1)
LS2.A: Interdependent Relationships in Ecosystems	The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. (5-LS2-1)
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems	Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, and water, from the environment, and release waste matter (gas, liquid, or solid) back into the environment. (5-LS2-1)
Crosscutting concept: **Energy and Matter**	Matter is transported into, out of, and within systems. (5-LS1-1)

National Research Council, 2012 https://www.nextgenscience.org/pe/5-ls2-1-ecosystems-interactions-energy-and-dynamics

Objectives

Students will be able to:
Define *matter,* elements of the *food chain*, and *decomposition.*
Identify matter that can be decomposed, and organisms that can decompose it.
Research and **present** their own findings of food chains in different ecosystems.

Materials

1. Computers and/or tablets (1 for each individual student)

2. (Learn) Introduction: Matter, the Food Chain, and Decomposition
3. (Play) Beat the Decomposition Clock
4. (Observe & Explore) Under the Scope
    a. Decomposing leaf (open as a PowerPoint, do not view in Google Slides)
    b. Decomposing badger
5. (Research and Present) Food Chains Across Ecosystems

Optional, Additional Resource for Differentiation

1. https://online.kidsdiscover.com/unit/ecosystems

Sequence

(Group) Hook:

- Students enter the classroom and are seated. Teacher may use an appropriate hook to begin the lesson about decomposition (such as asking where the Fall leaves go at the end of the season).
- Teacher then presents the advance organizer to help students anticipate their learning.

(Group) Present:

- Students open up the first section of the module on their individual technological device. With direction from the teacher, the class works through the *(Learn) Introduction: Matter, the Food Chain, and Decomposition* interactive lesson.

(Individual) Practice:

- As practice, the students work through the next two sections of the module, *Play* and *Observe & Explore*, gaining teacher feedback from observations and redirection.

(Small Group) Produce:

- Students will be put into groups and assigned one of 4 ecosystems: Desert, Ocean, Rainforest, or Wetland. They will independently (with their groups) research the assigned ecosystem and design a visual representation of the food chain on google slides.
- *Optional differentiation: For students who may struggle with finding resources, the teacher may provide the following link as a starting point: Kids Discover Ecosystems.*
- After preparing their visual and presentation scripts, the student-groups will present their slide to the class, and the teacher can provide feedback.