5-2022

It Takes Brains: Cultivating the Learning Process for Effective Science Communication

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IT TAKES BRAINS: CULTIVATING THE LEARNING PROCESS FOR EFFECTIVE SCIENCE COMMUNICATION

by

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A Doctoral Document

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Plant Health

Major: Plant Health

Under the Supervision of Professor Gary L. Hein

Lincoln, Nebraska

May, 2022

IT TAKES BRAINS: CULTIVATING THE LEARNING PROCESS FOR EFFECTIVE SCIENCE COMMUNICATION

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University of Nebraska, 2022

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Learning is a complex, subjective process. An important perspective on learning is that anyone, regardless of their level of education, can participate in learning about science and contribute to their community. The public increasingly looks towards online resources to find answers to challenges, so it is necessary that people become empowered to take information about issues rooted in science and apply them to their own lives and communities. In my experiences as a learner and educator, understanding the learning process provides a framework to design successful learning environments.

Since the brain is the organ most closely associated with the process of learning, learning environments should be modeled to reflect how the brain learns. Brain biology research reveals the nature of learning as four fundamental actions: information gathering, reflective thinking, creating meaning, and testing ideas. These four pillars of learning should be used to support lifelong learning needs of society by adapting the learning environment to the needs of a learner and their individual learning process. The purpose of this document is to present a framework based on the four pillars of learning to strengthen the design of online learning content and better address learning needs of the individual, adult learner. This framework has been applied to the development of online modules addressing the genetics of the development of pesticide resistance.

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CHAPTER 1

Brain-based Learning

Introduction

Learning is a complex, subjective process that shapes one's view of the world. Considered an innately human ability, it has allowed the human species to survive and prosper with the evolution of science (Liebenberg, 2014). An important perspective on learning is that anyone, regardless of their level of education, can participate in learning about and contributing to science. This perspective challenges traditional theories of learning and may have far-reaching implications for how scientific information is communicated and presented to the public. As one ages and accrues meaningful learning experiences, they become an active participant in different processes through which new knowledge and skills are gained. Learning experiences are what build the foundation of prior knowledge that forms one's perspective. This view is unique to every individual and acts as a lens that filters our interactions, ultimately determining motivation, our values, and actions. Every person has a wealth of knowledge obtained from learning experiences that accrue throughout their lifespan. The theory of lifelong learning shows that learning experiences are not confined to childhood or the formal classroom, instead the theory recognizes learning as a lifelong pursuit that occurs in all manner of settings (Falk & Dierking, 2019).

The theory of lifelong learning also tells us it is not feasible to equip a person with all the knowledge and skill needed to succeed throughout life while in school. In fact, if learning occurs across an individual's lifespan, a lot of that learning must occur outside of traditional school. Education has been an essential part of every society, and structured learning has aided humanity by communicating what we know and how we know it. There is a continuous need for knowledge and a lifelong need to learn, more than what can be supported through childhood and 12 years of school alone.

This need for continued education into adulthood cannot be supported by current learning means, such as attending regularly scheduled classes or obtaining a higher degree. How, then, do I propose to support lifelong learning needs of society? New paradigms are evolving in how information is disseminated and accessed by the public. In the past, people turned to libraries to get answers to their questions. This was accomplished through a trusted librarian or turning to stacks of literature to research. Today, with the Internet one has access to a vast amount of knowledge at their fingertips. Creating online learning experiences that act as supplemental educational opportunities that are relatable, relevant, and reliable can offer highly accessible resources for science communication and continued education.

Educational psychology offers a variety of theories and perspectives about the way learning occurs and assists in understanding learner expectations and intentions. Learners, particularly adult learners, bring unique characteristics to a learning experience. The term pedagogy refers to the theories and methods used in education, in many cases referring to the teaching methods for children and young adults (K-12). In contrast, andragogy acknowledges factors that influence learning throughout life, recognizing how adults learn differently and largely independently (Knowles, 1978 & El-Amin, 2020).

In my experiences as a learner and educator, understanding the learning process and its cycles provides insight to support learning. This is especially true in an online setting, where certain components of the learning process inhibit social aspects of learning, and guidance from the educator can be limited. Additionally, lessons from the past decades have illuminated the need to shift the focus of science communication away from solely informing the public to involving individuals in dialogue surrounding the problem. The purpose of this document is to:

1. Present a framework based on the four pillars of learning to strengthen the design of online learning content and better address learning needs of the individual, independent learner.
2. Demonstrate how scientific knowledge can be used to support adult learning and how online science communication can support the lifelong learning needs of an ever-evolving society.

Several scholars have described different cycles involved in human learning, each with their own interpretation of its purpose and the learner's role. These scientists share core beliefs about what they study and how they view learning. They make predictions on patterns in learning that are observable and can be understood through systematic study. In this chapter, components of these educational scholars' work are integrated into a framework of learning that offers direction to support the educator in designing online content that results in successful learning experiences.

Defining successful learning experiences

Humans have been exploring the brain and its inner workings for centuries, searching to unlock the mysteries of the mind. There are entire fields dedicated to understanding the brain and human consciousness. Branches of psychology, neuroscience, and educational research can be integrated to create an interdisciplinary perspective that depicts processes that take place as we learn. It would be hasty to recommend a formula or *modus operandi* for success when it comes to designing successful learning experiences. It is far more complex than a teaching moment and requires diligent planning, coordination, and compassion from the educator to facilitate the learning process.

The primary components of the learning experience are the learner and the learning environment. Our understanding of learning has changed a lot over the last century, but the role of a learner has remained largely the same in education. Traditionally, education has been teaching-centered where the learner's role as student is to learn through instruction and guidance of a teacher. The direction of the learning experience is determined by the teacher and the student has a passive role in their learning. While this method of instruction can be appropriate for some learning experiences, a student can be impeded later in their ability to pursue learning goals without a teacher or instructor to guide learning or provide reliable sources of information. Andragogy emphasizes the learner's role, providing a theoretical base for the examination of major concepts in learning theory (Fornaciari & Dean, 2014). In the case of online learning, learner-centered approaches are more sustainable and effective at supporting learning experiences (Ware, 2006).

The role of the online learner

The adult learner brings their unique biological makeup and a foundation of prior experiences that their knowledge is built on. These aspects of the learner need to be considered when developing a learning experience. The learner's perspective plays into their expectations of a learning experience and the intention of a specific learning outcome. For an educator or content designer, the priorities of the learner become important in developing learning goals and successful outcomes. Within this learning metatheory, learning occurs in a continuum from meaningless to significant, including personal engagement to self-initiate learning. There are various roles a learner must take on, and generally are described at four levels: (1) the dependent learner, (2) the interested learner, (3) the involved learner, and (4) the self-directed learner (Kazachikhina, 2019).

Dependence on an educator to facilitate the learning process is influenced by the learner's interest and prior learning experience. Interest plays heavily in motivation to learn, so interested learners will actively participate in a facilitated learning process under the direction of an educator. An involved learner actively pursues learning experiences and is motivated to learn, but the learning process is managed and monitored by the educator. The cognitive and emotional connection to learning established self-directed learning (SDL) theory, where the learner alone, based on their unique perspective, knows what is important for them to learn. SDL is a mental process or ability that a learner uses to direct their learning, gain knowledge, and understand how to solve problems (Long, 1994). American educators, Knowles (1975) Houle (1961) and Tough (1971), further developed SDL, emphasizing minimally-guided instruction and the need for collaborative goal setting. Self-directed learners actively engage in the learning process and are therefore largely independent of an educator. Garrison (1997) portrays SDL as an approach where the learner is motivated to assume personal responsibility for the learning process and collaborative control with the educator. Garrison's model of SDL consists of three skills required of the learner:

1. Self-management: one's ability to seek and manage their learning experiences and an understanding of their responsibility to reach learning goals.

2. Self-monitoring: one's ability to regulate their own learning process to construct cognitive meaning and reflect on thinking.
3. Motivation: one's ability to initiate and sustain effort towards achieving learning goals, reflecting the learner's perceived value of the learning experience.

Managing a learning experience requires learner proficiency and interdependence in constructing personal meaning. Educators support self-management by incorporating learner input into shaping goals and promote independence in providing context to the experience. Asynchronous online environments provide flexibility for a learner to set their own pace and is a benefit online learning. This provides the ability to plan their learning strategies at the time and place that is most effective. Synchronous online learning (e.g., live chats or virtual classrooms) allow the learner flexibility to choose place and settings. An educator can design an experience to allow for independent learning by offering a range of resources for support in the learning environment.

To self-monitor learning, the learner must direct themselves to gain knowledge and create connections. Self-directed learners tend to search online for resources (Teo et al. 2010) which presents more opportunities to access reliable, relatable resources. But it also presents the learner with less than reliable sources. Therefore, it becomes the responsibility of the learner to sort through misinformation and false facts to prevent bias. The learner must participate in self-observation, self-critique, and self-reflection to regulate their learning process and reach meaningful learning.

In SDL, motivation is defined by personal and contextual characteristics that describe what compels people to learn and how people are moved to continue learning. Intrinsic motivation is inherent to an individual and drives the direction of one's behavior and self-determination. When a learner experiences the inherent satisfaction of learning and forming meaningful connections, intrinsically motivated behavior results. If a learner is completing an activity to attain some reward, like grades or recognition, they are extrinsically motivated.

Emotions play a vital role in motivating learning, creating memories, and influencing decision-making (Damasio, 2003). Positive emotions through successful relationship building, motivation, vision and purpose, involvement and engagement, and exciting learning experiences are important in facilitating learning experiences (Li et al., 2020). Den Ouden et al. (2013) demonstrated that the hormone dopamine, a neurotransmitter, increases pleasure to reinforce learning in the long term. In fact, when a person solves a problem themselves, they release a surge of neurotransmitters like adrenaline and dopamine. Asking questions relevant to the learner has the same effect, and this surge of emotion creates a sense of excitement (Stahl, 2002). The role of the educator in reinforcement is to create an environment that enables these positive emotions. Motivation is closely linked to positive emotions, and when persuasive learning has the opposite effect, hormone release can create resistance to learning (Sagarin et al, 2002).

Motivation in learning theory

Maslow's theory of motivation was first proposed in 1943, presenting a hierarchical approach to human motivation. This model (Figure 1.1) had an immense influence on the field of psychology and continues to be cited in textbooks. Maslow's hierarchy of needs offers the educator or content creator a perspective of the learner to consider when designing content and considering learning goals. This allows the educator to direct their ideas and content into a learner centered design. This gives space to a learner to allow them to be motivated to learn individually and change their perspective through actions. Maslow views human motives based in an innate and universal lens. His ideas were revised by Kenrick et al (2010) who continued from Maslow's fundamental motives under two core ideas:

1. There are multiple, independent motivational systems that are fundamental to human behavior, and
2. These motives form a hierarchy in which some motives have priority over others at different times.

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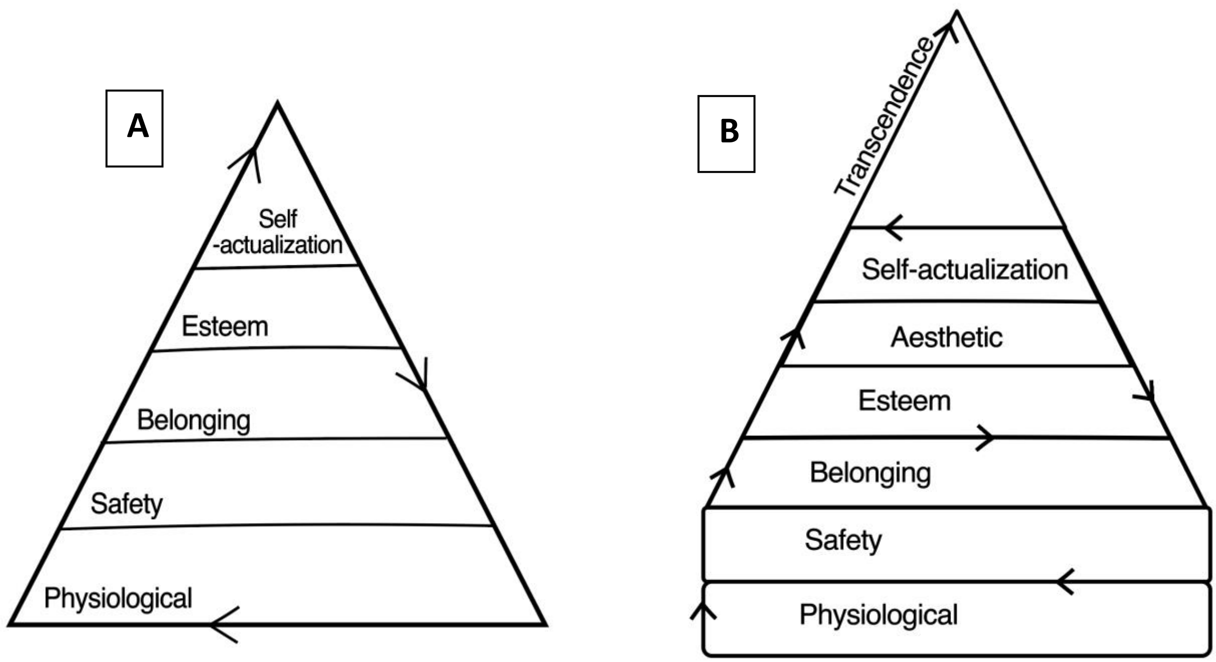

Figure 1.1 Original (A; Maslow 1943) and revised (B; Kenrick et al. 2010) hierarchy of needs

In practice, this hierarchy of needs allows an educator a wide perspective of the learning process that can be used to adapt the presentation of knowledge based upon learner needs. For example, a potato grower that is concerned about crop injury from an infestation of insecticide resistant beetles is not invested in learning about the biology of the beetle or how selection pressure resulted in resistance in their field. They are likely thinking about management to preserve their yield and prevent future crop injury. The grower's perspective of the learning experience is framed by a fundamental need as safety motives drive behavior. While knowing the beetle's biology is important in understanding how selection pressure can prevent future crop infestations, this knowledge needs to be framed in a way that is relatable to the learning needs of the learner.

Maslow's hierarchy is not a universal approach, as learner needs are subjective and the result of genetic structure, life experiences, and emotions. Learning styles are as unique as individuals. The same concrete experience that enters the mind through sensory input is translated into the nervous system as something entirely different from the perspective of another person. The recognition that everyone experiences learning differently is the nature of human needs. By allowing individual learning processes to occur, a learner-centered approach is integrated to meet learning needs and objectives. When initial SDL models were developed, face-to-face instruction was the predominant mode in education. Online learning experiences can provide students with great SDL opportunities (Fahnoe & Mishra, 2013) and offer convenience (Poole, 2000) and flexibility (Chizmar & Walbert, 1999). There is relative ease of access regardless of who a learner is, where they are, or when they can participate. This redefines educational opportunities for those least well-served by traditional continuing education to give more control of the instruction to the learner (Garrison, 2003).

The learning process

Educational psychology offers a variety of theories and perspectives about the way learning occurs and assists in understanding learner expectations and intentions. One of the most cited experiential theorists, Kolb (1984), emphasizes that learning is the basic process of human adaptation and details how a learner's experience, their perception, cognition, and behavior form the basis of the learning cycle. His experiential view of learning as a process to scaffold knowledge involves creative skills to navigate four learning modes. These four modes offer insight into how to support learning to bolster knowledge creation and connections.

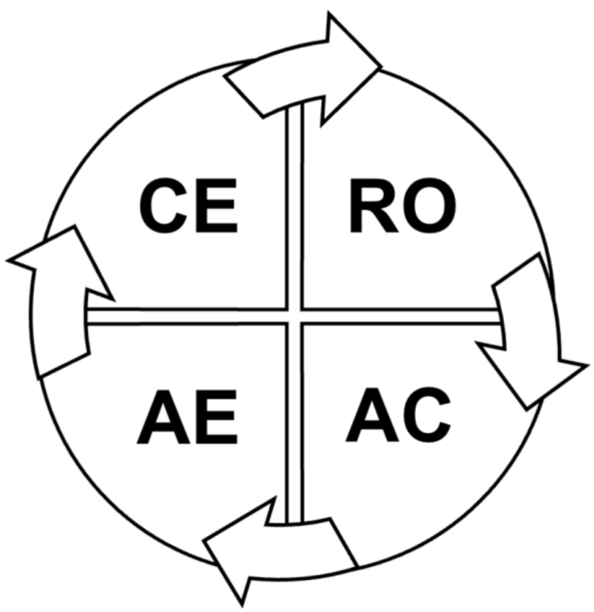

Figure 1.2. The four modes of Kolb's cycle of experiential learning (Kolb 1984).

CE: Concrete Experience, RO: Reflective Observation,

AC: Abstract conceptualization, and AE: Active Experimentation.

These four modes of Kolb's cycle of experiential learning (Figure 1.2) are dependent on context in the learning environment: (1) a concrete experience, (2) reflective observation, (3) abstract conceptualization, and (4) active experimentation. In a successful learning experience, a learner mediates reasoning and arranges understanding between concrete experience and abstract conceptualization of an idea. A similar structuring of understanding is in flux between reflective observation and action, forming a learner-centered balancing act that drives the learning cycle.

Concrete experiences are the direct interaction with the world and provide learners with a tangible piece of information with physical attributes from which to build abstractly. The physical input is observed from different perspectives and reflection on the experience forms connections and ideas, i.e., abstract conceptualization (Kolb 1984). A learner must be able to use these connections and ideas to make decisions and solve problems. Understanding these key processes of the learning cycle provides an opportunity for intervention and developing tools to support learner needs.

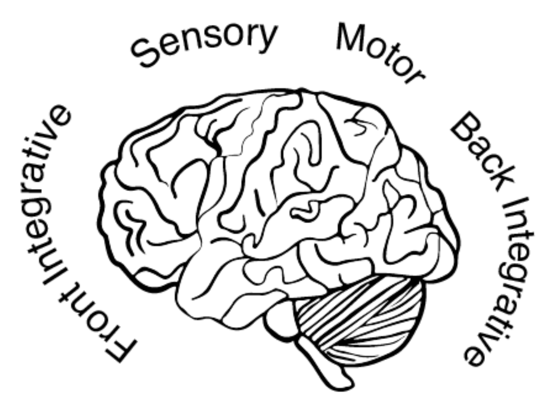

Figure 1.3 The four areas of the brain involved in the learning process.

The brain is the organ most associated with the ability to learn. In every brain, human or not, there are sensory elements that respond to outside stimuli (input), motor elements that generate action, and association elements that link the sensory and the motor together (Figure 1.3). Neuroscience tells us that all nervous systems function similarly. In humans, the areas of the brain connected with the learning process are the sensory, motor, front integrative, and back integrative regions of the neocortex. Sensory organs input new information to the brain, which utilizes association to link the sensory stimuli with an appropriate motor response. Recent advances in imaging technology have enabled researchers to map the anatomy of the highly complex organ and observe what happens in the brain with certain behaviors, emotions, and processes of thinking. Psychiatrist Norman Doidge's (2007) work on brain plasticity demonstrated that the brain is not rigidly hardwired but changes as one learns. What is unique about the brain circuitry is its ability to form and reform connections through experiences and mental activity. (Doidge, 2007)Dr. James Zull, a biochemist and director at the University Center for Innovation in Teaching and Education, explored what brain biology reveals about the nature of learning. He theorized that Kolb's learning cycle (Figure 1.4) correlates with current understanding of brain functioning. Zull (2002) discusses the link between the experiential learning cycle and neuroscience research of brain functioning.

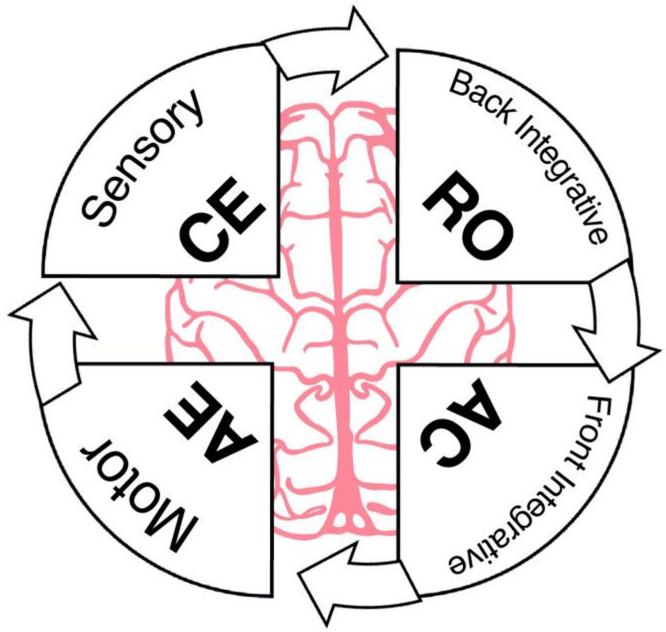

Figure 1.4: Brain circuitry, integration, and correlation with Kolb's experiential learning cycle as proposed by Zull (2002).

In Zull's theory, the learning cycle arises from the structure and function of the brain. Concrete experiences become input to the brain, coming through the sensory cortex. Reflective observation involves arranging the new information and comparing it to prior knowledge, which occurs in the integrative cortex at the back of the brain. This reflection and connection to prior knowledge creates new abstract concepts (thoughts) that occur in the frontal integrative cortex. This is followed by active experimentation that involves the motor region of the brain (Zull, 2002: 18; Kolb & Kolb, 2008). The nature of change discussed by Zull details the physical changes occurring in the brain as we learn. Zull suggests that learning is powerful and long-lasting in proportion to how many neocortical regions are engaged. The more regions of the cortex engaged during learning the more change will occur. Learning experiences need to be designed to use the four major areas of neocortex, thus, Zull identifies four fundamental actions in the learning cycle (Figure 1.5).

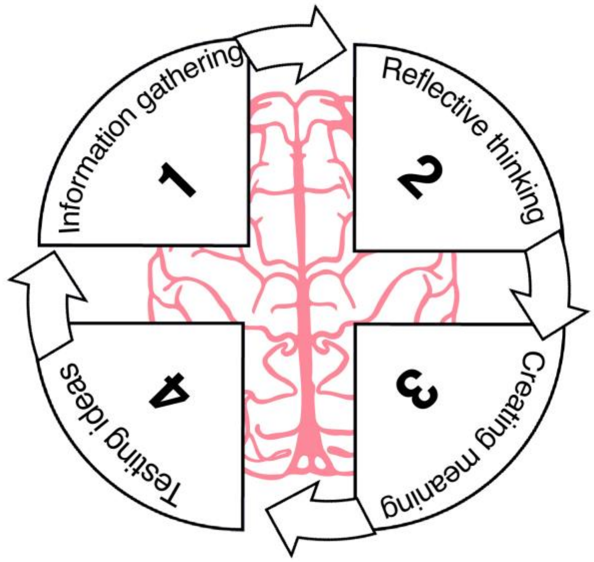

Figure 1.5 Learning cycle and the four fundamental actions.

I. *Information gathering:* The first of the four pillars identified by Zull (2002) is fundamental in understanding where a person seeks information and what one perceives as essential for learning. Gathering information is associated with the sensory cortex, which is responsible for sensing new information. Sensing does not immediately lead to understanding, but it is an important component of overall learning processes. To learn, people need to be actively involved with the world around them to have access to concrete experiences and meaningful interactions. This method to “absorb” and assimilate the information is used in situations like surviving, socializing, and of course learning a language. The gathering of data, within any learning experience, is a critical step which should include the activation of all senses (Table 1) and it should hopefully originate from concrete experiences (Zull, 2002).

Vision	Sensory inputs from the eyes are mapped by the brain and grow into mental representations (images) that then underlie cognitive ability and thought. Gives most precise spatial input on the world around us (see it to believe).
Auditory	Arguably the core of language, human hearing contributes to cognitive and emotive mapping information of inputs.
Touch	Physical sensations can act as a substitute for vision. The neocortex creates maps of anything within reach to provide data about texture, hardness, solidness, weight, etc.
Smell and taste	Provides qualitative information sensed through our emotive systems. Sweet or sour, fragrant, or putrid all trigger different emotions. We experience these in our body and these can then be interpreted as feelings.

Table 1. Sources of sensory input to the brain that can be utilized to support the first pillar of learning by engaging the brain in the experiences.

The more senses involved in any learning situation, the more regions of the brain are activated. Thus, if more senses are involved in the gathering of data, these processes activate more neurons; therefore, the activation of neural connections leads to the creation of complex networks within the brain. Data collected by the sensory neocortex are bits of useful information by themselves, but data collection is not equal to learning. In sum, to be most effective, the brain relies on its biological mechanisms to gather data through a complete sensory-based experience. Learning styles should focus on senses involved in data gathering, and data collection by each of the senses has its own value.

II. *Reflective thinking*: Once the brain has received and gathered information from the environment, these data need to be connected to make meaning of the information. The assimilation of all the pieces of data occurs by creating associations with prior information learned. Basically, the data which entered the brain through the 5 senses is "grouped" with other pieces of data to form information that is used to develop meaning. This process is fundamental in the learning of a language due to its connective nature of grouping. It is in this stage where the learner creates connections between the new data with existing knowledge in the brain. For example, if a person looks at grass, they may see the color green, feel the texture of the leaves, and recall the smell of it freshly cut. This implies that these bits of data were grouped together as memories experienced through senses and combined to give an abstract idea of the physical object.

New knowledge is also classified based on its relevance for that specific experience, as well as related to the recall of previous knowledge coming from the memories of the learner (Sousa, 2011). Similarly, this reflective stage of the learning process is the one which facilitates and produces memory formation due to the connectivity nature of its functioning. In simple words, the brain connects the incoming information with the already processed information by means of reflection.

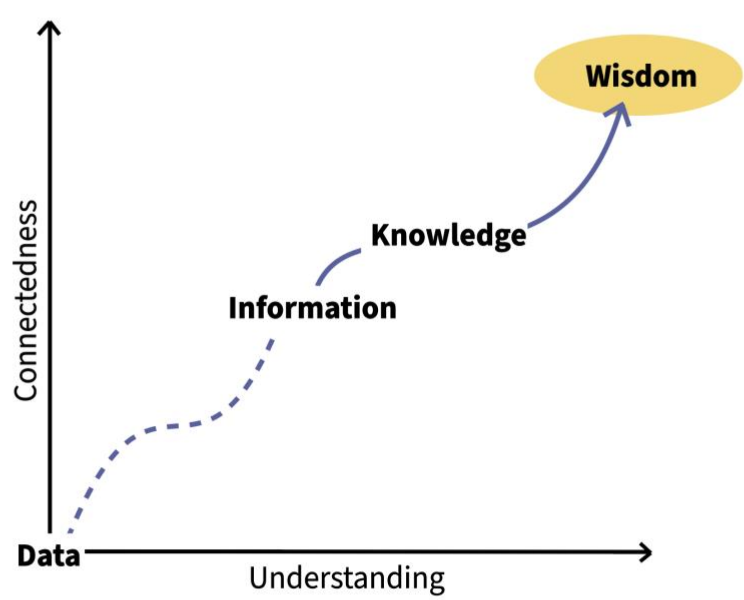

Figure 1.5 Pathway of data input to the brain that accumulates as information and is connected to form knowledge that leads to the wisdom and deeper understanding

New data flows from the sensory neocortex toward the association regions in the back of our brain, where bits of data are merged into groupings (Figure 1.5) that accumulate as information to produce knowledge (Zull, 2002). Associations categorize and label objects and actions to identify the relationships inherent among them through reflection. The slowest part of learning tends to be the assembly and association of bits of data and memory, which takes time and reflection. The area of the back integrative cortex is heavily involved in estimating the relative value of objects, experiences, and people. Associations also occur between memories as well as new sensory input, thus full comprehension of learning depends on associations between new events and past experiences. The greater the reservoir of past events to be drawn on, the greater the meaning to the individual.

Memory is a critical factor in learning and consists of forming neural networks that are later accessed through a complex matrix (Benfenati, 2007; Willis, 2006). New pathways connect and influence old pathways through activation and association (Kahneman, 2011), but from the educator's point of view, it is hard to predict the learner's exact neural associations. This raises questions in understanding how information is integrated into a learner's memory and how it is accessed later to solve problems or create new ideas. An educator needs to be capable of connecting the learner's prior knowledge to new content by asking questions that excite and motivate learning.

III. *Creating meaning*: At this stage, the brain performs processes related to solving problems and abstract planning. Moreover, it creates intentional and purposeful associations. It is in this stage where we form a hypothesis and develop action plans to be performed with the information planted by the learning experience. Creating meaning is what a learner will actively do with the data and information they have received. Most of these action plans will be tested out in the next stage; however, this plan is not just a list of steps. Taken as a whole, it is a theory or an abstraction of the mind. Such plans, theories, and abstractions consist of a combination of images and language. Abstractions are the result of intentional associations, selected, and manipulated for a purpose. This is the function of the front association cortex, which represents perhaps the most elevated aspects of learning. The front association cortex is responsible for intentions, decisions, and judgments that are all required for development of deep understanding. Students at this point think and consciously observe the usefulness and benefits of learning a specific topic, as well as what they can do with that information (Zull, 2002).

IV. *Testing ideas*: This pillar encases the testing of the action plans originated in the previous stage. It is in this stage where learners can observe if their predictions or hypothesis from the previous stage hold strong. The student can finally try their ideas out in the real world after receiving, associating, and planning what to do with the stimuli they received. If the action plans for some reason fail, they can start the process again and retest their ideas. This pillar, like the first, has the experience-based foundations of Zull's model of learning. Its relevance originates from the concrete usage of the information after all the internal systems dealt with the stimuli entering the body. In sum, students need to be given time to try out their ideas in a concrete and active manner.

Testing out personal theories is a final step in learning and understanding. It must be active and use the motor regions of the brain. It needs to complete the circuit of the theory and be tested by action to discover how our understanding matches reality. Without testing knowledge, the information received is not utilized or developed into a unique idea. Writing ideas down and discussing them are forms of active learning, as the physical action produces a signal from the motor cortex that the body then senses. This changes the mental idea for a physical event, and it changes an abstraction once again into a concrete experience.

Conclusion

Developing online learning experiences that support the learning process and promotes accomplishment of learning goals is no easy task. The goal of education is to support the learning process, and the subjective nature of learning presents the educator with challenges in designing an environment that supports the learner and promotes the self-directed process. Scholars have recently turned their attention to the importance of SDL skills for online learning experiences, enabling learner capabilities to regulate the learning process. The level of self-direction needed may change in different contexts, such as a person's familiarity with the topic or their interest in the content. According to Candy (1991), the learner may exhibit a high level of self-direction in an area related to a prior experience. It could be argued that the goal of online education is to develop the self-directed learner and guide them to learning resources.

While the learning process is complex, there are tools the educator can utilize to implement the process in the learning environment. Kolb's (1984) experiential learning cycle presents a framework for the learning process, which demonstrates that the learning process is predictable. The four pillars presented by Zull (2002) can be utilized to support lifelong learning needs of society by adapting the learning environment to the needs of a learner’s individual learning process. The pillars present opportunities for support in the learning process where the educator can develop informative, online content that presents reliable information to the learner in an effective manner. Online learning lends itself to an SDL experience, where the learner needs to be in control of planning their learning pace and monitor their own comprehension and progress. Online learning often situates implementation of learning and management of the experience with the learner. To make judgements of various aspects in the learning process, the educator must develop strategies to effectively present resources to overcome challenges that are uniquely associated with online learning content.

CHAPTER 2

Integrating the four pillars of learning into online learning

Introduction

Science, the knowledge accumulated by centuries of learning through observations and research, is a shared resource for information. It is essential to communicate this information to society in response to profound challenges such as the current climate crisis, environmental degradation, resource scarcity, and the ongoing COVID-19 pandemic. Today, agriculture faces formidable challenges that tests sustainability, competitiveness, and resilience. Scientific advances fuel progress in agriculture and have contributed to ensuring a long, healthy life.

In the United States, computer-controlled technology has become a normal aspect of daily life. Science has given society products controlled by technologies that are constantly upgraded and reimagined, but these technologies often are not fully understood or appreciated. Limitations in access to science-learning experiences have resulted in a psychological distance from science. This distance can be seen in public interactions surrounding scientific information, such a theories surround climate change, the use of pesticides, genetically modified organisms, or the COVID-19 pandemic. Current theories in psychology suggest that an individual's psychological distance from science is influenced by their perception of the scientific topic or event and how they process and relate to that knowledge (Chen & Li, 2018; McDonald, 2016; Spence et al., 2012). Online science learning opportunities provide experts and science educators opportunities to reduce this psychological distance by connecting with and involving the public in learning.

The public increasingly looks to online resources for answers to challenges, so it is necessary that people become empowered to take information about issues rooted in science and apply them to their own lives and communities. Gathering information and applying it to their individual learning process can require support, which is where the learning environment has an impact on the learner. To support the process, the learning environment needs to present science-related information as engaging, relatable to the individual, and relevant to the public. Successful engagement relies heavily on the educational process, and a critical part of this process is establishing an effective learning environment.

The four pillars of learning presented by Zull (2002) can be integrated into the design of effective online learning environments to support the brain's learning process. The more regions of the brain that are engaged, the more effective a learning environment. The four areas of the neocortex (sensory, back-integrative, front-integrative, and motor) correlate with the four fundamental pillars of learning: information gathering, reflecting on meaning, creating connections, and testing ideas. This chapter details how the educator can design content that supports the learning process by activating certain areas of the brain.

Growing connections with learning needs

When designing online learning environments, the interests of the target audience must be determined, along with the audience's current level of understanding. This involves determining where adult learners enter the learning process based on community needs. This is accomplished by performing a learning needs analysis. After the goals and the required resources have been determined, a needs analysis will:

1. Identify essential resources currently available,
2. Identify resources that to be developed,
3. Identify topics of importance in the community.

These surveys seek to gather accurate information that is representative of the needs of a community. Taken before designing content, it highlights current situations and identifies deficits in learning opportunities. This establishes a foundation that is vital for the learning environment and allows the educator to strategically design content that will meet the learner where they are in the learning process.

Engaging the brain through the learning environment

Pillar 1: Gathering Information (Activating the sensory cortex)

It is important to remember that gathering information does not immediately lead to understanding. While reading, the text received as data by the brain through the eyes is just that: data. The words, by themselves, have no useful meaning and must be interpreted by the brain. Taking a multisensory approach can help the brain interpret the written data. The educational goal is to design content to engage the sensory neocortex by using real experiences to provide concrete examples of the information.

Humans gather information firsthand and secondhand. Firsthand experiences are initiated through direct sensory input to the brain from the environment. When identifying an insect on a plant, I observe its characteristics with my eyes. I see its coloration, its size, number of legs, wings, and the shape of its antennae as data points that my brain uses to create an image of the insect in my mind. With this firsthand information I can identify the insect, but I need secondhand information from a source to infer whether it is a pest species or beneficial to the plant. When creating online learning content, the opportunities for firsthand experiences become complex to illustrate. To support information gathering, it is important to incorporate realistic experiences into learning content by providing multiple visual and concrete examples of information with text, visuals, and audio.

One useful approach to organizing learning content is to consider the breadth and depth of information being presented. Breadth refers to the full span of knowledge of a subject, depth refers to the extent to which specific topics are focused upon and explored. Within any learning experience, there will be both breadth and depth of knowledge required that increases as one advances their learning. Is the content at an introductory or advanced level? What level of understanding is asked of the learner? Anderson et al. (2001) presents a continuum that represents a range of knowledge from concrete (factual) to abstract (meta cognitive) (Table 2.1). Factual knowledge consists of the basic elements a learner must know to connect with a topic or solve problems involved. This level includes knowledge of terminology and specific facts. Conceptual knowledge consists of the interrelations of factual knowledge within a larger structure. It includes knowledge of theories and principles that enable basic elements to function together. Procedural knowledge consists of knowing a specific skill, technique, or method as well as the criteria for using them within the topic. Metacognitive knowledge is personal awareness of one's own capabilities within a subject, such as knowing strategies to accomplish a task using specific skills.

Factual Knowledge:	Knowledge of terminology Knowledge of specific details
Conceptual Knowledge:	Knowledge of classification Knowledge of principles

	Knowledge of theories, models, and structure
Procedural Knowledge:	Knowledge of specific skills Knowledge of specific methods Knowledge of criteria
Metacognitive Knowledge:	Strategic knowledge Self-knowledge

Table 2.1 Knowledge continuum presented by Anderson et al. (2001) that represents a learner's level of understanding of a topic.

The educator can add context to the learning environment by setting learning objectives. Learning objectives articulate the knowledge and skills a learner will gain as a result of a learning experience. It informs the learner of what key information and ideas are important to know, what skills will be developed, and what connections can be made beyond the learning experience. Creating an online environment that promotes both learning objectives set by the educator and learning goals of the individual learner is no easy task. The learning goals of the individual learner allow for self-assessment and provide personalized context for the learning environment. There must be clear communication from the educator at the start of the learning experience where the learners are tasked with thinking about and identifying their own specific learning goals as well as the learning activities they would use to meet these goals (Hanna, 2000). Some learners may not be accustomed to determining individual, personal learning goals within the context of the topic and in a learning experience. Suggesting that the learner draws on current or past experiences to relate their learning activities to their current life situation is a good way to help the learner focus on their learning process.

To focus the design and function of the content, Conrad and Donaldson (2004) suggest that learning content in the online environment should be focused on learning objectives that utilize the mid to higher levels of Bloom's taxonomy such as application, analysis, synthesis, and evaluation (Bloom et al, 1956). The framework from "Taxonomy of Educational Objectives" (Bloom et al. 1956) consists of six major categories (Table 2.2) with the categories after knowledge representing skills and abilities in learning.

Taxonomy of Educational Objectives Bloom et al (1956)	A Taxonomy for Teaching, Learning, and Assessment Anderson et al (2001)
Knowledge "Recall of prior knowledge"	Remember - Recognizing - Recalling - Describing
Comprehension "Ones understanding of what is being communicated to make use of knowledge"	Understand - Interpreting - Explaining - Summarizing - Inferring - Comparing
Application "Use of abstract in a concrete setting"	Apply - Executing - Implementing
Analysis "Scaffolding or relating knowledge and ideas"	Analyze - Differentiating - Organizing - Attributing
Synthesis "Reconstructing knowledge to form a whole understanding"	Evaluate - Checking - Critiquing
Evaluation "Judgment of material or content for its purpose"	Create - Generating - Planning - Producing

Table 2.2. Original (Bloom et al. 1956) and revised (Anderson et al. 2001) taxonomy of learning objectives.

	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual	List	Summarize	Respond	Select	Check	Generate
Conceptual	Recognize	Classify	Provide	Differentiate	Determine	Assemble
Procedural	Recall	Clarify	Carry out	Integrate	Judge	Design
Metacognitive	Identify	Predict	Use	Deconstruct	Reflect	Create

Table 2.3. Knowledge types help to determine desired learning objectives.

Anderson et al. (2001) revised and updated Bloom's commonly used and well-respected assessment tool to reflect the advances in cognitive psychology and educational research that have occurred since it was first published (Table 2.2). The revision of Bloom's Taxonomy allows a dynamic conception of learning objectives and uses action verbs and gerunds to describe the cognitive process by which learners encounter and work with knowledge (Table 2.3). This table can be helpful to develop learning objectives and decodes the use of the appropriate verbs for certain activities. One might be able to recite the periodic table of elements or a listing of scientific names of insects but generating a list does not demonstrate understanding or ensure a successful learning experience. As a learner develops knowledge and connections through learning, they become capable of analyzing content and evaluating its meaning. They can connect elemental names to chemical bonds or insect species to pest management practices, demonstrating a deeper understanding of its purpose.

Pillar 2: Reflective thinking (the integrative back cortex)

In the previous chapter, we explored how the sensory cortex gets information in small bits that are later reassembled. Important parts of this reassembly take place in the integrative back cortex. In terms of the learning cycle, this integration process involves reflecting on meaning. We stand back from a concrete experience, examine it, and think about it. In Kolb's (1984) experiential learning model, reflection is the key for learners to transform concrete experiences into abstract concepts. The task for an educator is to help students during this process.

As sensory input flows, data are merged into combinations that begin to produce a meaningful image. Associations occur between memories as well as sensory data, thus comprehension depends on the associations between new events and past events. The more past events available to be drawn on, the more powerful the meaning. Ausubel (1968), Bloom et al. (1956), and Piaget (1945) focus their studies of psychology on how humans learn. They sought to understand the internal processes of acquiring, constructing, and retaining knowledge and theorized that learning occurs as one reorganizes experiences, making meaning of new input from the learning environment. Ausubel (1968) introduced his meaningful learning theory (MLT) to educational psychology. In MLT, a learner is considered the center of the learning process, and the focus is on connecting new information to prior knowledge through reflection (da Silva, 2020). To make a learning experience meaningful, an educator should make content relatable and relevant to learners across a wide demographic.

The assembly of associations built between bits of data and memories can be considered a slow part of learning. It takes reflection to make meaning. We now know what parts of the brain are active when we reflect on an image. When we reflect, we bring up images from our past experiences and search to create connections. It is not solely the learner's role to reflect and make experience "into" learning. It is also the educator's responsibility to adequately recognize their learning as meaningful in this perspective.

Reflection can be activated through the learning environments structure by including scaffolding, reframing, and discussion. It can also be included on a timeline through retrospective reflection (reflecting on past actions), contemporaneous reflection (reflecting on the activities in-action), and anticipatory reflection (reflection on future actions). Reflection enables the learner to generalize the main ideas of the topic, its principles, and abstract concepts from experience (Kolb, 1984). In an online learning environment, using embedded prompts in content and answers with feedback guide learner reflection (Chang, 2019).

Using reflective dialogue facilitates knowledge creation and is typically used to generalize practical examples from information presented in the content. During reflective dialogue, an experience is re-thought for perspectives to shift and requires practice to improve. To make decisions about the use of new information, a person must step back and reflect on how they make conscious decisions and solve problems. The learner must use abstract thought to apply information and decide if a set of strategies is appropriate or if problem-solving might be improved. This process requires the learner to personalize their understanding of the content and rationale of what they have just learned. Framing reflection as a process to retrieve, apply, and analyze knowledge and then relate it to larger issues, allows the learner to step back and reflect on what information they have gathered.

When a learner is thinking reflectively, they repeatedly retrieve the information from memory and retention is increased. To support this thinking, educators can help externalize the mental process by prompting the learner to reflect on what they have done before, during, or after an experience (Lin et al., 1999). There are several themes that can be used to prompt reflecting on meaning, and each will have different impacts on learning.

A) Increasing the depth of knowledge – require reflection at the end of activities (review and revisit knowledge gained to reinforce connection and conceptualize experiences).
B) Identifying the areas which are missing or deficient – reflect on areas that were unclear or 'muddy' (reflections shared on community blogs allowed others to understand public interests and potential projects for improvement).
C) Personalizing and contextualizing knowledge – reflect using personal experiences and emotions (how to apply knowledge in practice).
D) Providing comparative references in learning – reflect on how other people have used the knowledge (reflections on community blogs also allows the public to see different perspectives of the learning experience).

Using reflection embedded in designed tasks can help learners see the interconnections of the knowledge they are learning. Reflection that is embedded in the progressive design of the assignment (one assignment serves as the foundation for the next one) allows the learner to see structural connections.

Pillar 3: Creating meaning (stimulating creativity in the brain)

We know that creating meaning takes place in the front integrative cortex, which is also the part of the brain that is most active in solving problems, creating connections, and assembling ideas into plans. The information and meaning developed must now be consciously internalized through cognitive skills. When new information reaches this area of the brain, we comprehend its meaning then apply and attach our own thinking to it. This is also when relevance is identified and usefulness of the learning experience itself is decided. The learner must make decisions on the possible ways they can apply the information they have just gained.

To best support the third pillar, the learning environment needs to engage learners and promote creativity. Adult motivation and engagement are influenced by personal and contextual factors that drive them to seek information to problems or challenges they have prioritized. Related to Ausubel's MLT, Piaget's theory of problem-based learning (PBL) uses cognitive constructivism that evolved into a learner-centered model that emphasizes accessible, interdisciplinary learning experiences (Savery, 1995). The role of the educator in both MLT and PBL is to guide learners in framing ideas, structuring learning, and assessing knowledge development. The central idea of PBL is that a learner connects to content that is relevant and captures real-world problems, prompting abstract thinking as they acquire and apply new knowledge to complex problems. Using community interests and values to develop a learning activity makes real world problems relevant to the immediate needs of the learner. This helps to specify rationales for learning that are also aligned with the course.

Pillar 4: Testing ideas (motivating action in the neocortex)

The motor area of the neocortex allows us to react to the inputs our brain initially receives and interprets. This is an active process where the learner tests the connections and ideas originated in the previous stage. Active testing of connections can take many forms, so new actions can produce new experiences from which learning will continue.

Language is the primary way we convert our ideas into actions, and speech demands more of our motor brain than any other action. We may also write out ideas, act them out, or make drawings of plans or images. When we test our ideas, we are changing the abstract into concrete. Converting mental ideas into physical events forces our mental constructs out of our brains and into the reality of the physical world. Stories and their dialogue impart information by activating learner emotions and increasing receptiveness to information. Personal stories are humanizing, and the narrative at the heart of a good story is also a powerful form of communication. Stories can convey technical information in a more accessible manner for the public and allows the individual to create relevant connections.

The purpose of a story can be to entertain, persuade, inform, or express an idea about the theme of the story. The listener engages active listening skills to follow the narrator's point of view in the story and the description of characters. Neuroscientists Stephen et al. (2010) found that when telling a real-life story, the brains of the storyteller and the listener exhibited similar patterns in neural activity in the same area of the brain. This implies that successful communication is a shared activity that results in transfer of information between brains.

In my experience as a learner and educator, the ability to tell the right story at the right time is a useful communication skill. Dialogue uses skillful storytelling to help listeners understand the essence of complex concepts and ideas in meaningful and often personal way. Practices of narrative building and recognition of prior learning are necessary in the design of learning activities. The building blocks of a narrative are:

- Entry point: compelling objects/assets, problem, puzzling question, or choice,
- Engagement: ask questions, explore, investigate, make observations,
- Resolution: solution, answer, call to action.

Translating complicated concepts that are jargon-heavy into terms and ideas to which the learner can relate through a story is not always easy. The first step is to frame the topic in a bigger theme that is relevant to the learner and community. It could be environmental, public health, or related to economics. As an example, the topic of beneficial soil microbes ties into several major themes like soil health, food-security, and climate change. Secondly, the storyline needs to be connected to the topic. Consider how the topic can creatively link to challenges facing humanity and specifically the community being presented the information. A learning environment needs to appeal to the learner's personal beliefs and emotional understandings of the world to make an impact on and help them connect to the information being communicated.

Conclusion

Only the learner knows their own ideas, so only the learner can test them. Part of the art of creating online learning environments is the art of eliciting action without social interaction. Since the learner is in control, they will not act unless they want to do so. Educators can support the learner through the learning environment by designing content that activates the learning process. The personal nature of the learning process and how emotions come into play to motivate action can also address this challenge. Emotions like interest, confusion, and awe can be used to grab a learner's attention. Presenting information that is relatable and relevant can maintain that attention. People are motivated when they feel competent and can identify personal connections to the information they are learning. The four pillars of learning demonstrate a framework for content design and successful transfer of information to the learner. This framework has been applied to the development of online modules addressing the genetics of the development of pesticide resistance. One of these modules is presented as a case study for the application of these learning concepts to the development of optimal online learning environments.

CHAPTER 3

Applying the four pillars to online module development

Introduction

The previous two chapter provided insight into the four pillars of learning and how the educator can support the learner through content design. To demonstrate the successful transfer of information to the learner, the information previously presented has been applied to the development of online modules. These modules address the genetics of the development of pesticide resistance. The first of these modules is presented as a case study for the application of the four pillars to the development of optimal online learning environments.

To help the transfer of this knowledge to educators and content designers, the following checklist has been developed as a framework to guide development of learning environments. Beginning with setting the stage, content is designed for the self-directed learner and presented in a relatable storyline that enables further reflection and inspires the development of new ideas. Each of the four pillars is highlighted by a color, which later corresponds with the color of comments in the case study.

Checklist for educators

While designing content, use this list to check that your material utilizes these tools:

Pillar 1: Information Gathering	Pillar 2: Reflective Thinking	Pillar 3: Creating Meaning	Pillar 4: Testing Ideas
		☐ **Self-Directed Learning (SDL)** Focus on engaging learner with material to demonstrate how the course fits their goals. (pg. 8)	☐ **Skillful storytelling** Storyline frames the topic in a bigger theme relevant to learner and community. (pg. 35)
☐ **Learning Objectives** Utilize Bloom's revised taxonomy to communicate with the learner. (Table 2.3)	☐ **Meaningful Learning Theory (MLT)** The learner is the center of the learning process (pg. 32)	☐ **Engages learner to create ideas** Content guides the learner to frame ideas, structure learning, and assess knowledge development. (pg. 34)	☐ **Active testing of new connections** Use of language (speech, writing, or drawing) to act out ideas and convert mental ideas into physical events. (pg. 34)
☐ **Diverse use of sensory input** (i.e., use of graphics, images, video, and audio Table 1.1)	☐ **Reflective Dialogue** Learner is prompted to reflect on the information that has been presented. (pg. 34)	☐ **Problem Based Learning (PBL)** Content uses relevant, real-world problems to prompt abstract thinking and create connections to information. (pg. 34)	☐ **Questions that test higher order thinking** Bloom's taxonomy can also be used to write questions that inspire action and discussion. (Table 2.3)

Case Study

Pesticide Resistance Management
Genetics: The key to pesticide resistance
Unit 1 | Module 1
Trait expression

Overreliance on pesticides to control agricultural pests (insects, diseases, and weeds) has caused pest populations to evolve through the application of selection pressure. Individuals with a higher tolerance for pesticides survive to reproduce – increasing the proportion of resistant individuals that will eventually outnumber the ones that are controllable.

Problem based learning captures real-world problems and sets the stage for the learning experience, specifying rationales for learning.

In these lessons, we discuss the role of genetics in the development of pesticide resistance. There will be four modules discussing trait expression, genotypic inheritance, and phenotype, the origin of resistance, and selection pressure.

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Articulate the skills learners will use through learning objectives.

Learning objectives

At the completion of this module, each student should be able to:

1. **Describe** a gene and its involvement in the basic steps of trait expression.
2. **Differentiate** between the processes of transcription and translation.
3. **Reflect** on the process of DNA replication and how it relates to mutations.
4. **Predict** how mutations in genes and their expression can control resistance to a pesticide by insects, diseases, or weeds.

Ask the learner to set learning goals that can be used to measure progress.

Personal Learning Goals

Setting personal learning goals support the learning journey until you reach your desired outcome. Learning goals can be broad, general statement on what the purpose of a learning experiences is to you and should provide direction and focus. Your goal should be personal and tailored to your individual learning needs and strengths.

Stories and their dialogue impart information by activating emotions.

Introduction

Take a moment and observe Figure 1. What do you see? If a farmer was walking through this field, what would he/she think? The living plants in the picture are the weed kochia (*Bassia scoparia*). Looking closely, they would see many dead kochia plants in this field because it was treated with an ALS herbicide. But most of the surviving kochia plants in this field grew from seeds that were distributed the year before by a single plant as it tumbled and turned with the prevailing wind. If the farmer had applied ALS herbicide the year before to kill kochia and other weeds, the success of this weed control method would motivate them to repeat it this year. The farmer may have been pleased with the ALS weed control last year, but likely not this year.

Through guided visualization, learners can create a mental image in the absence of an actual experiences.

Figure 1. A trail of healthy kochia plants growing in the field after a single herbicide-resistant plant shed its seed as it tumbled across the field in the wind. (Photo by Andrew Wiersma, Colorado State University)

By using prior knowledge and background experiences, readers can connect with a picture.

Why is this occurring? The farmer is observing the results of biological history that they have been a part of developing. The kochia plant, growing in the field the year before, possessed a **gene** that had mutated to create a new version or allele. When this mutant allele was expressed, it encoded a **protein** that interacts in a different way with the ALS herbicide. This different interaction allowed this plant to survive the herbicide treatment and continue its life cycle. By the time it died at the end of the growing season, it had successfully produced hundreds of seeds. After it was no longer alive, its seeds tumbled with it as the wind moved it across the field and distributed its seeds. Many or most of the seeds had inherited the herbicide resistance allele and they too were able to resist the farmer's herbicide application.

Reflective thinking is a process to retrieve, apply, and analyze information and then relate it to larger issues.

Traits

Understanding why the ALS herbicide resistance trait was expressed in some of the families of kochia plants in our farmers field, but not in others, requires us to understand trait expression. Trait expression, sometimes referred to as the **central dogma**, is the process by which the instructions in **DNA** are read in the cell to build a functional **protein**. The mystery of why unique characteristics or traits in animals and plants could appear across generations was solved when early molecular geneticists discovered the identity of genes. Genes are specific sequences of DNA nucleotides that are part of a **chromosome**. These geneticists determined that genetic information flows from a DNA sequence to an amino acid sequence, creating proteins that accomplish specific functions inside cells. The function of these proteins controls the traits we observe in organisms.

Genes are passed from one generation to another. The most obvious examples of **gene** inheritance occur when a single gene controls variation in a trait. Very simple patterns of gene inheritance can be observed with traits such as flower color in plants. In other instances, there can be a range in the expression of a trait. In Figure 2, the three plants have all been exposed to the same herbicide treatment, but they express a range of resistance to the treatment.

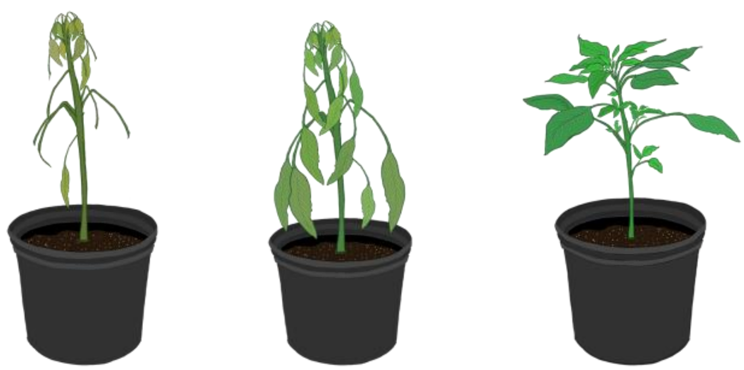

Figure 2. Range of reactions from an application of glyphosate to these Palmer amaranth plants. They range from killing the plant (left), to injuring the plant, to having no affect because of resistance (right).

Traits and Trait Expression

The process by which the DNA instructions are read by the cell to encode a functional protein is called trait expression. Trait expression is the flow of genetic information from DNA to RNA to protein.

Unit 1: Module 1: Video 1: Traits

Watch this short video to help you picture the connections between genes, trait expression and traits.
https://use.vg/zjLdnm

Using video and audio involves more senses. The more senses involved in any learning situation; the more regions of the brain are activated.

Trait expression has two central stages – transcription and translation.

Genes are part of the huge macromolecule called the chromosome. Hundreds or even thousands of genes can be part of the same chromosome. Because of their size, chromosomes remain in the nucleus during the trait expression process. The building of proteins happens in the cytoplasm of the cell. Thus, trait expression requires a two-step information transfer process. The first step in the transfer of genetic information is transcription.

During transcription, the DNA nucleotide sequence of the gene is read to build an RNA message (**messenger RNA or mRNA**) with a corresponding nucleotide sequence. In this step, DNA making up the chromosome is unwound, and a specific gene is targeted for expression. Transcription enzymes read the DNA and assemble mRNA – which is then moved outside the nucleus for translation.
The mRNAs travel from the nucleus to the ribosomes, where they are read by this protein building machinery, and the information encoded in the mRNA is used to build the amino acid sequence that forms the protein.

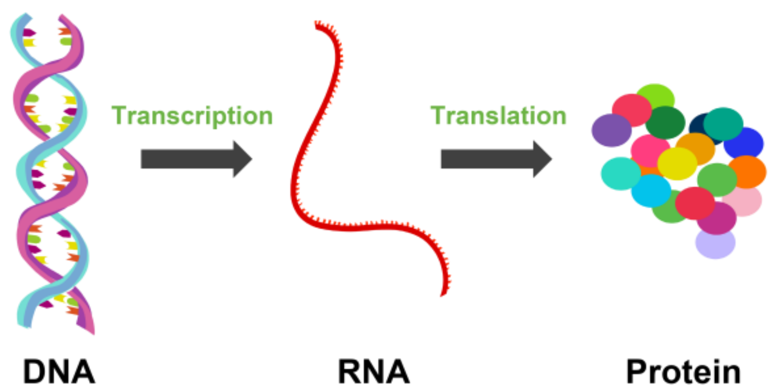

Figure 3. Flow of information from DNA to the formation of a protein.

These images are used to represent abstract concepts of DNA and trait expression, helping to create a mental image of the information presented.

Transcription (*DNA to mRNA*)

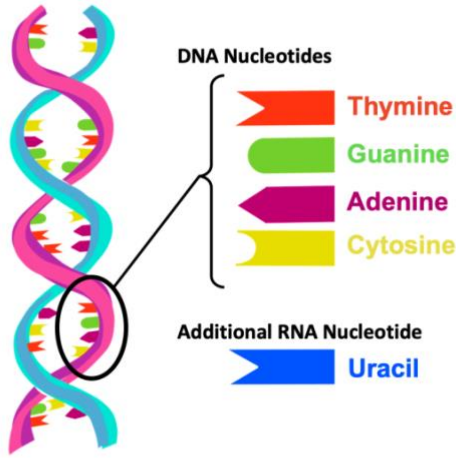

Figure 4: DNA stores genetic code as a sequence of the four different DNA subunits called nucleotides. These nucleotides are: thymine, guanine, adenine, and cytosine. There is also an additional RNA nucleotide where, during transcription, uracil is swapped in for thymine.

During transcription, the DNA sequence of a specific **gene** is read by the enzyme **RNA polymerase**, which builds a complimentary messenger RNA (**mRNA)** strand. One distinction in this process is that thymine nucleotides in the DNA will be converted to uracil nucleotides in the complimentary mRNA. These new mRNA strands are smaller and more mobile than DNA and are easily transported outside of the nucleus. The result of transcription is that the mRNA will be read to determine the specific amino acid sequence of a **protein** in the process of **translation**.

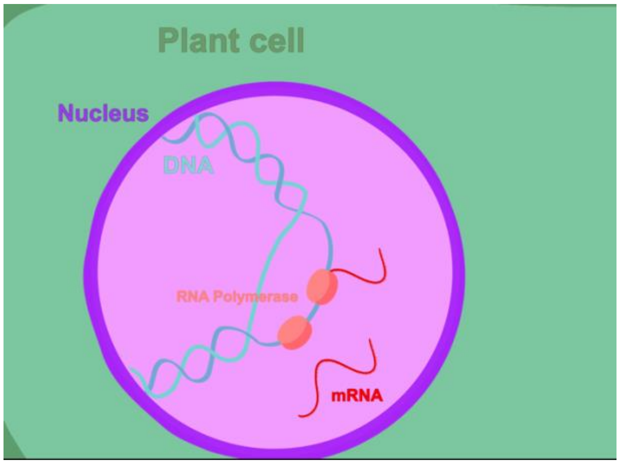

Figure 5. Transcription occurs in the nucleus of the cell. RNA polymerase binds to the promoter region of the gene and reads the DNA nucleotide sequence of the gene, producing an mRNA strand. Once it reaches the termination sequence, the RNA polymerase falls off. As a result, the complimentary strand of mRNA is created and transported outside of the nucleus.

Videos can create opportunities for reflective thinking and reviewing challenging content.

Unit 1: Module 1: Video 2: Transcription

Trait expression is the process by which genes becomes proteins, and it occurs in two parts: transcription, and translation. This video describes the process of transcription.
https://use.vg/LAOyOs

Translation *(mRNA to proteins)*

Translation is the process of reading the sequence encoded in the nucleotides of the **mRNA** to build the amino acid sequence of the **protein**. The synthesis of the proteins is directed by the newly transcribed mRNA and is completed with the help of a **ribosome**.

Presenting information at multiple levels by using descriptive imagery helps the learner connect to abstract processes like transcription and translation.

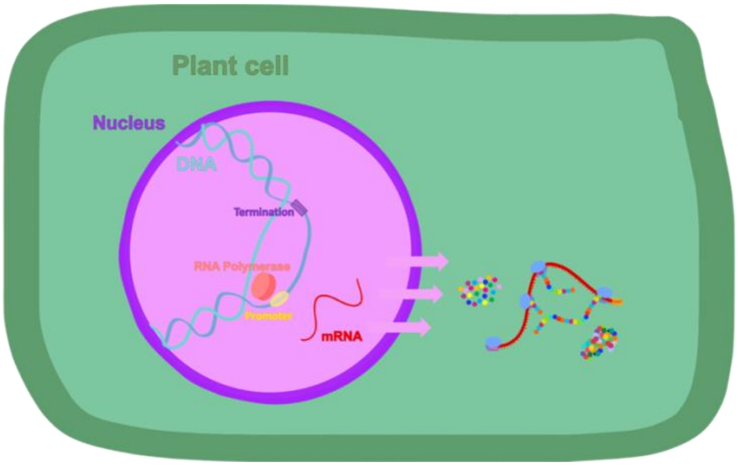

Figure 6. mRNA leaves the nucleus and enters the cytoplasm for the translation process.

Once the mRNA moves outside of the nucleus into the cytoplasm of the plant cell, ribosomes attach to mRNA and translation begins.

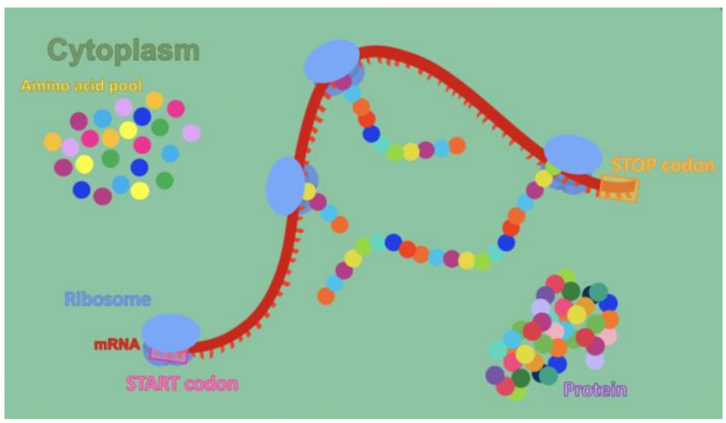

Figure 7. mRNA made during transcription is "decoded" to build a protein that contains a specific series of amino acids.

During translation, the ribosomes read the information in a mRNA sequence in groups of three. These groups of three mRNA nucleotides are called codons.

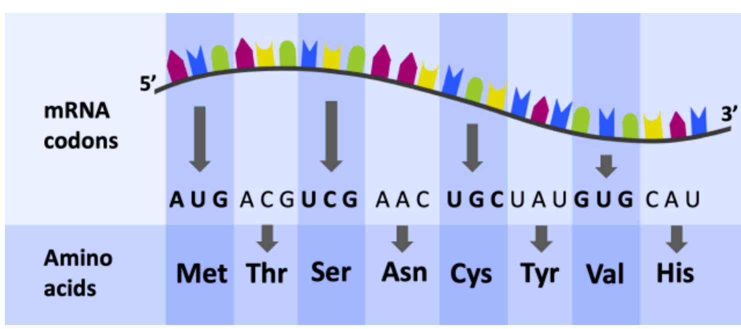

Figure 8. Codons in the mRNA encode specific amino acids in the protein.

One codon, methionine (Met), always acts as a start codon to signal the beginning of protein construction. It signals where the ribosome should bind to start translation. There are also three stop codons that tell the ribosome when a protein is complete. Every codon between the START and STOP codons specify which amino acid the ribosome should add next from the amino acid pool. There are 64 possible codons in the triplet code, but only 20 amino acids need to be encoded. Each amino acid is coded by one to six different codons.

Unit 1: Module 1: Video 3: Translation

This video describes the process of translation.
https://use.vg/YrhYbb

Prompt the learner to generalize main ideas, principles, and concepts from the learning experience as a form of reflective thinking.

Here is a recap of translation:

Getting started: Ribosomes assemble around the mRNA and bind to the start codon to initiate translation.

Extending the chain: Ribosome read the mRNA, building the protein one amino acid at a time. An incomplete protein is called a polypeptide chain. As the ribosome reads the codons, it adds the corresponding amino acid to the growing protein chain.

Termination: This is when the finished protein is released at the stop codon of the mRNA sequence. After being released, the protein chain folds into the 3D shape of a protein and is moved to the place in the cell where the protein can perform its function.

When we write out ideas, act them out, or make drawing of plans or images - we test our ideas and change the abstract into concrete.

Learning Activity – Trait Expression
This hands-on activity reinforces the processes of transcription and translation. Using the information you've gathered thus far in the learning process, create drawings of the steps of trait expression:
DNA → mRNA → Protein.

Include the following terms in your sketches:
DNA, Nucleotides, Gene, mRNA, Ribosome, Start Codon, Promoter, RNA polymerase, Termination Sequence, Stop Codon, Amino Acids, Protein, Nucleus, Cell Wall.

DNA Replication and Mutations

Why does DNA replication occur?

Help the learner to create ideas by promoting problem solving and assembling ideas into plans.

When plants and animals grow, they get bigger by adding more cells to their multicellular body. This requires a cell division process called mitosis. Before a cell divides, its DNA is copied (replicated). This is a fundamental process occurring in all living organisms.

The process of **DNA replication** is performed by the enzyme DNA polymerase. During DNA replication, DNA polymerase reads the DNA sequence from the existing nucleotides and builds a complementary DNA strand. For this to happen, other enzymes work together to unwind the DNA into two strands, where both strands of the double helix act as templates for the formation of new DNA molecules.

Figure 9. Double stranded DNA unwinds and is replicated by DNA polymerase and other enzymes.

As shown in Figure 9, the double helix of the original DNA molecule separates (blue, purple) and new strands (green) are made to match the separated strands. The result will be two DNA molecules, each containing an old and a new strand.

Can mistakes occur during DNA replication?

Gene mutations

A mutation is a change in the DNA sequence that makes up a **gene**. Mutations can arise if a mistake happens during replication. The rate of mutation is very low because the DNA replication process is accurate. But because an organism has so many cycles of replication as they build and replace cells during their lifetime, it is common for multicellular plants and animals to acquire mutations in some of their genes from these random mistakes made during replication. Mutations in DNA create new alleles, or different versions of that gene. Mutations can be harmless, detrimental, or beneficial for the organism. What is important about mutations is that they can create new genetic variation among members of a population, and this genetic variation may provide a selective advantage to individuals that make up a population.

Figure 10. Movement of ALS-resistant kochia across a field.

Let us return to our farmers field that was the home for a kochia weed population. Imagine this: A mutation occurs during the replication of a new cell in a kochia plant as the cell is developing into a seed embryo. This mutant allele is now found in almost every cell of the new plant as it grows. By chance, the mutation was in the gene that encodes the protein targeted by the herbicide used by the farmer. This small change in the mutant allele still encoded a protein that had the structure to perform its normal function in the plant, but now it no longer had a structure that promoted interaction with the herbicide. The result is that the herbicide will no longer have its intended impact on the plant, and the plant will be resistant to that herbicide. This is an example of a mutation that would have a beneficial impact for the plant. The scenario just described was the series of chances that led to a kochia plant surviving herbicide treatment. However, there are other possible consequences of random mutations.

Mutations can have one of two outcomes on the protein: the change in DNA sequence can have no effect on the protein (silent mutation) or it can affect the protein by changing its structure and function (point mutation or frame shift mutation). This change in protein structure caused by the mutation of the DNA can have different impacts on the plant depending on the environment it is growing in.

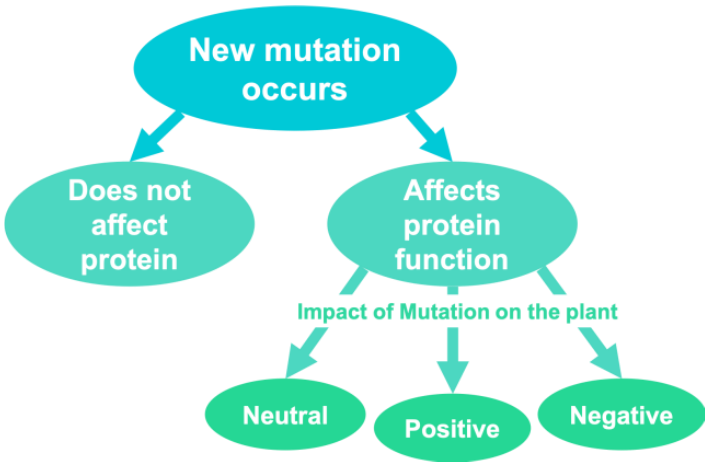

Figure 11. Possible impact categories for mutant alleles.

There are three major effects that a mutation has on the final protein:

1. **Neutral effect:** there is no obvious impact on the phenotype of the plant and is seemingly unchanged.
2. **Positive effect**: impact of the mutation on the plant has a beneficial effect.
3. **Negative effect**: impact on the plant is detrimental and could potentially kill the plant.

These outcomes are dependent on the environment in which the plant lives. If a mutation occurs that aids the weed's ability to resist a usually harmful pesticide like an ALS herbicide and the grower does not apply any ALS herbicide to their fields, then the impact of this mutation is not visible and is neutral. Once the grower applies an ALS herbicide, however, the mutation's impact on the plant changes from a neutral one to a beneficial one.

If the mutation in the gene encoding the ALS herbicide target protein results in the protein losing its beneficial function in the plant, this mutation will have a negative effect on the plant. Whether the plant encounters the ALS herbicide or not, this mutant allele would have a selective disadvantage for the plant. The plant may not be able live long enough to complete its life cycle, and this mutant allele will not be passed on to future generations.

Provide comparative references from real world examples to illustrate complex, abstract ideas.

What different kinds of mutations lead to these changes in the effect of mutation? ALS inhibiting herbicides work by binding to an ALS enzyme that is key in the production of amino acids. Research that includes the sequencing of DNA from different kochia (*Bassia scoparia*) plants that were resistance to ALS inhibitors, such as Classic, revealed that the mutations changed a single amino acid in the ALS enzyme. This small change in the protein resulted in a change in target site sensitivity to the herbicide's presence.

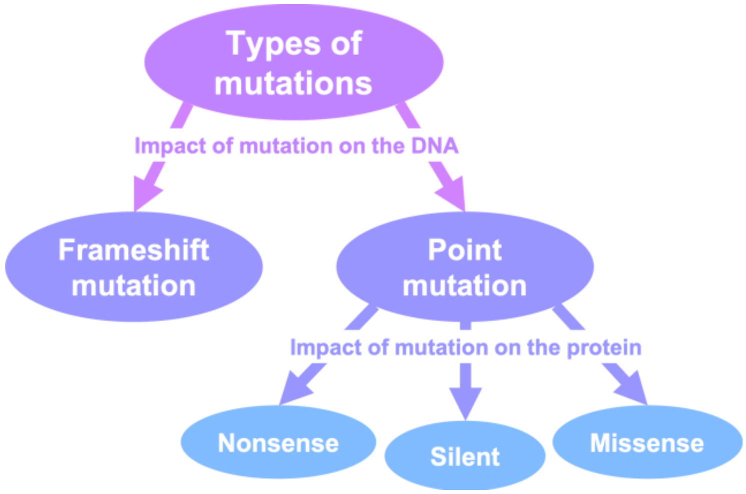

Figure 12. The impact of mutant alleles can be placed into these four categories.

Frameshift mutations are mutations that can result in the addition or deletion of nucleotides in a gene. Because these mutations will affect the codon originally containing that mutation and all subsequent codons in the gene, they likely have a major impact on the protein encoded by the mutant allele. Point mutations result from changes in a single nucleotide in the DNA sequence. There are three types of point mutations and each can have a different effect on the final protein. We'll discuss this in terms of ALS inhibitor herbicide resistance in kochia:

1. **Silent mutation:** the mutation changes a single nucleotide in the DNA sequence and has no effect on the final protein. There is no effect on the structure of the ALS enzyme and the kochia maintains its target site sensitivity and remains susceptible.
2. **Missense mutation:** the mutation in the kochia changes a single nucleotide in the DNA sequence, which results in changes in the amino acid. This alters the structure of the enzyme enough that the ALS herbicide can no longer bind, creating herbicide resistance. Depending on how the protein functions and whether the ALS inhibiting herbicide is being applied, this specific missense mutation can either have a negative, neutral, or positive effect.
3. **Nonsense mutation:** If there is a single nucleotide mutation that changes a codon that would normally code for an amino acid into a stop codon, it halts the construction of the protein. If a plant cannot survive without this enzyme, the mutation has a detrimental effect on the survival of the kochia plant. Because the plant will not survive, this mutation will not reproduce in the plant population.

Unit 1: Module 1: Video 4: Mutations

A brief overview of mutations and the effects on DNA
https://use.vg/yiVVrM

Increase depth of knowledge by requiring further reflection at the end of the learning activity by revisiting knowledge to reinforce connections.

Mutations are a part of all life. There is no organism on the planet that has a perfect, error free system for replicating their DNA. So, while mutations are rare, if an organism is abundant, the chances are some individuals in a population will have mutations occur and possess mutant alleles. This motivates us to look a little more closely into the consequence of these four types of mutations at the molecular level.

Prompting the learner to create connections between the information presented about gene expression, mutations, and pesticide resistance.

The activity below will describe each of the mutations then give you a question that will ask you to apply the genetic fact to a weed resistance situation.

	Gene expression	Frameshift mutation
DNA	A C G T C A G C G C A T G C A	A C G T C A A G C G C A T G C A
mRNA	U G C A G U C G C G U A C G U	U G C A G U U C G C G U A C G U
Amino acid	Cys Ser Arg Val Arg	Cys Ser Ser Arg Thr

Figure 13. Frameshift mutations change the order in which the nucleotides form codons. This reading frame shift changes the entire amino acid sequence in the protein after the position of the mutation.

	Gene expression	Point mutation
DNA	A C G T C A G C G C A T G C A	A C G T G A G C G C A T G C A
mRNA	U G C A G U C G C G U A C G U	U G C A C U C G C G U A C G U
Amino acid	Cys Ser Arg Val Arg	Cys Thr Arg Val Arg

Figure 14. The point mutation shown above substitutes the amino acid threonine (Thr) for serine (Ser). This single amino acid change may or may not change the structure and function of the protein.

	Gene expression	Point mutation
DNA	A C G T C A G C G C A T G C A	A C G T G A G C G C A T G C A
mRNA	U G C A G U C G C G U A C G U	U G C A C U C G C G U A C G U
Amino acid	Cys Ser Arg Val Arg	Cys Thr Arg Val Arg

Figure 15. The point mutation shown above substitutes a single nucleotide but occurs in a position that creates a stop codon. The new protein encoded by the mutant allele will be shorter than the 'normal' protein.

	Gene expression	Silent mutation
DNA	A C G T C A G C G C A T G C A	A C G T C A G C G C A C G C A
mRNA	U G C A G U C G C G U A C G U	U G C A G U C G C G U G C G U
Amino acid	Cys Ser Arg Val Arg	Cys Ser Arg Val Arg

Figure 16. The point mutation shown above substitutes a single nucleotide in the mRNA but has no effect on the amino acid sequence of the protein. This can happen because the genetic code is redundant. There are 64 possible codons in the triplet code and 20 amino acids need to be encoded. Each amino acid is coded by one to six different codons.

Active testing of new connections and converting ideas into action

Quiz

Question 1

Question: A frameshift mutation occurs in the gene encoding the ALS protein. The change in the ALS protein's amino acid sequence is shown in Figure 13. Assume that this change happens after the first 200 amino acids of the 600 amino acid protein. What will be the biological result of this mutation?

- A. No biological impact
- B. The protein will not be functional and the plant may not survive
- C. The protein will probably be functional and may provide a selective advantage in the right environment.

Question 2
Question: A point mutation occurs in the gene encoding the ALS protein. The change in the ALS protein's amino acid sequence is shown in Figure 14. Assume that this change happens after the first 200 amino acids of the 600 amino acid protein. What will be the biological result of this mutation?

- A. No biological impact
- B. The protein will not be functional and the plant may not survive
- C. The protein will probably be functional and may provide a selective advantage in the right environment.

Question 3
Question: A point mutation occurs in the gene encoding the ALS protein. The change in the ALS protein's amino acid sequence is shown in Figure 15. Assume that this change happens after the first 200 amino acids of the 600 amino acid protein. What will be the biological result of this mutation?

- A. No biological impact
- B. The protein will not be functional and the plant may not survive
- C. The protein will probably be functional and may provide a selective advantage in the right environment.

Question 4
Question: A point mutation occurs in the gene encoding the ALS protein. The change in the ALS protein's amino acid sequence is shown in Figure 16. Assume that this change happens after the first 200 amino acids of the 600 amino acid protein. What will be the biological result of this mutation?

- A. No biological impact
- B. The protein will not be functional and the plant may not survive
- C. The protein will probably be functional and may provide a selective advantage in the right environment.

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