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Cognition and Learning

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Section 1: Introduction

How do students learn the anatomy and physiology of dogs and cats, cows and horses, and lemurs and dragons? How do students become proficient at typical behavioral procedures such as physical exams, diagnostic testing, and essential surgeries? How do instructors create educational environments that foster long-term, meaningful, and integrated knowledge? These questions are common among veterinary medicine educators and the answer is always the same: **It depends.**

The science of learning and teaching is complicated and has a long history. The modern dawn of the science lies in the late nineteenth and early twentieth centuries, although its historical, educational, ideational, and philosophical roots go back much further. Currently, the science of learning and teaching is often explained through a series of canonical theories of human learning: classical and operant conditioning (behaviorism), social cognitive theory and information processing theory (cognitivism), and the emerging theories associated with cognitive neuroscience. This chapter will focus on cognitivism.

It should be noted, however, that cognitive science is not an "exact" science, as humans tend to be unpredictable and contextually bound, while the brain has yet to give up the wealth of its secrets. As George Ladd, President of the American Psychological Association, stated in the very first issue of *Psychological Review* in 1894, "all human science is but patches of a shallow, superficial stratum, dimly lit through occasional rifts in the clouds, over the fathomless depths of the ocean of reality" (Ladd 1894, p. 8). While Ladd's language is long on metaphor, the intent is clear: there is much yet to learn in human learning science, including cognitive science. Indeed, it is not possible to program a human being the way one might program a computer – the same inputs do not always result in the same outputs. One has only to teach a year or two in the classroom when it becomes apparent that a lesson taught at 10 am may foster significant student learning, while the same lesson taught at 2 pm on the same day, may fall flat. Why? It depends.

While I agree that "it depends" is a wholly unsatisfying refrain, it is accurate. This chapter will address issues of learning, memory, and cognition in general, and how they relate to instruction, in particular. However, it is not possible to state that if an instructor engages veterinary medical students in solving three problems, explaining two concepts, and writing one summary that all students will have learned the relevant content to a deep level – it depends. It will depend on

a) the prior knowledge of the students (i.e., are they novices or experts, is their knowledge well-integrated or fragmented?),
b) the attitudes of the students (i.e., are they fearful or confident in their studies, are they more likely to persistent in the presence of failure or give up?),
c) the engagement of the students (i.e., are they learning rotely or meaningfully, are they thinking and interacting actively or passively and individually or socially?),
d) the nature of the instruction (i.e., is it alienating or engaging, are the students motivated to engage with the learning process?), and,
e) the structure of the content itself (i.e., is the content simple or complex, is the content focused on concepts, procedures, or both?).

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Guidelines for learning and teaching always have an "it depends" asterisk because the effectiveness of guidelines always depends on the interactions between the students, the learning environment, and the content.

Finally, and with the greatest emphasis, "it depends" necessitates that instructors maintain an active role in the education of their students. Who knows best the students' backgrounds, prior knowledge, and dispositions; the contents' structure, relationships, and importance; and the instructions' purpose, organization, and delivery? The instructor does. It is the instructors who must make the application of the cognitive theories and findings to their classrooms, labs, and clinics, as well as informal discussions. As the psychologist William James (1899, p. 10), stated regarding the application of psychological theory to educational practice: "An intermediary inventive mind must make the application, by using its originality" – that is you.

Part 1: A Framework

The history of cognitive science is replete with experimental studies demonstrating that there is a relationship between how we think about our experiences (processing) and what we ultimately learn and can do (performance). This processing–performance relationship can be thought of as a framework designed to organize these various experimental findings into a coherent approach to the understanding of learning and the development of instruction. Frameworks are like theories in organization and purpose, but different in that they may be less systematic and less neat and tidy in representing a field. In this chapter, the processing–performance framework will be represented using the following mantra: **What we process we learn.**

Perhaps the best representation of this processing–performance framework is the concept of **depth of processing** proposed by Craik and Lockhart. In their framing paper (Craik and Lockhart 1972; see also Zinchenko 1939), they proposed that the *deeper* we process experiences, the better we remember them. This "depth" is represented by a continuum where processing can be shallower, based on superficial sensory or physical characteristics (attributes), or deeper, based on pattern recognition and meaning making (semantics).

This depth of processing concept was addressed empirically by Craik and Tulving (1975), who asked students to process words based on an *orienting question* designed to foster shallower or deeper processing. Specifically, participants were asked to answer one of three types of questions upon the presentation of a word: *case* questions (Is the word in capital letters?), *rhyme* questions (Does the word rhyme with ______?), or *sentence* questions (Would the word fit in the sentence: He met a ______ in the street.). A different sentence was provided for each word. The rationale behind the study was that a *case* question focused on a shallow or superficial (attributes) processing of the word, a *rhyme* question focused on an intermediate or phonetic processing of the word, and a *sentence* question focused on a deep or meaning-based (semantic) processing of the word. After answering a series of questions (e.g., case, rhyme, or sentence) in relation to specific words, participants were asked to either recognize or recall the specific words. What Craik and Tulving found (see Experiment 1) was that participants were able to recognize 16% of the case words, 57% of the rhyme words, and 89% of the sentence words. These findings were interpreted as evidence that the case questions fostered shallower processing resulting in less retention, and the sentence questions fostered deeper processing resulting in more retention. That is, how we process an experience influences what we remember from an experience (what we process we learn).

Over the next 50-plus years the concept of depth of processing (or what is sometimes referred to as levels of processing) has been criticized, lauded, expanded, and refined. Almost immediately upon publication, it was realized that there would be a need for an "index of depth" to determine the depth of processing of a particular task with some specificity (Baddeley 1978). For example, to what degree is analyzing a word for appropriateness in a sentence "deeper" than determining if a word rhymes with another? How do we know that problem-based learning is deeper than the use of flash cards? Unfortunately, such an index never materialized and current depth of processing experiments still use shallow and deep as their metric. Another concern regarding the depth of processing approach occurred when it was demonstrated that learning is not solely a function of the initial learning task (encoding), as proposed by Craik and Lockhart (1972), but rather, is also dependent upon the nature of and relationship to the subsequent performance task (retrieval).

This learning–performance (encoding–retrieval) perspective is evident in the research focusing on **transfer appropriate processing** (see Morris et al. 1977), which demonstrated that when the same type of cognitive processing occurs during both initial learning and subsequent performance, performance is enhanced. For example, Agarwal (2018) had students read eight short passages and immediately complete an initial *fact-based* multiple-choice test for four of the readings and an initial *higher-order-based* multiple-choice test for the other four readings. After a two-day delay, half of the students who initially completed a fact-based test completed a delayed fact-based test, while the other half of the students completed a delayed higher-order-based test. In addition, half of the students who initially completed a higher-order-based test after reading the passages completed a delayed higher-order-based test, while the other half of the students completed a delayed fact-based test. Thus, for some students, their immediate test and their two-day delayed test aligned (fact-based/fact-based, higher-order-based/higher-order-based), while for other students their tests misaligned (fact-based/higher-order-based, higher-order-based/fact-based). Students who initially completed a fact-based test after reading a passage did better when completing a delayed fact-based test (78%) than a delayed higher-order test (46%). Similarly, students who initially completed a higher-order-based test after reading a passage did better when completing a delayed higher-order-based test (72%) than a delayed fact-based test (53%). These results indicated that when the type of cognitive processing was the same during learning and performance, performance was enhanced – aligning of the learning and performance processing matters.

Similar to the transfer appropriate processing research, the research focusing on **encoding specificity** (see Tulving and Thomson 1973), demonstrated that when the same context is present at both initial learning and subsequent performance, performance is enhanced. For example, Godden and Baddeley (1975), had individuals learn lists of words either on land (dry) or underwater (wet) with the assistance of scuba gear, and then later recall the learned words either on land (dry) or underwater (wet). This procedure resulted in four conditions, (i) learned on land, recalled on land (dry, dry), (ii) learned on land, recalled underwater (dry, wet), (iii) learned underwater, recalled underwater (wet, wet), and (iv) learned underwater, recalled on land (wet, dry). Godden and Baddeley found that individuals recalled significantly more words when the learning and recall environments aligned (i.e., dry, dry and wet, wet) than when they misaligned (i.e., dry, wet and wet, dry). These results indicated that when the context was the same during learning and performance, performance was enhanced – aligningof the learning and performance context matters.

Taken together, depth of processing, transfer appropriate processing, and encoding specificity research demonstrates that the depth of processing, type of processing, and context of processing at the time of learning and performance matter. However, these concepts of processing depth, type, and context are not exact. There is no formula that mathematically models the effectiveness of their relationship. *What we process we learn* serves as a guide, a framework, to help understand that examining the nature of the learning process and performance matters. Thus, in general, veterinary students will be able to perform well in the clinic (or operating room) to the degree that their learning occurred in a similar situation, involving similar processing, and to a similar degree. As will be seen, learning and performance are impacted by a plethora of mechanisms and conditions. How? Unfortunately, it depends.

Section 2: Social Cognitive Theory

The intimate relationship between learning and performance is clearly evidenced in social cognitive theory. Social *cognitive* theory grew out of social *learning* theory, which had its roots in behaviorism. **Behaviorism** dominated the theoretical landscape of learning in the early twentieth century. Behaviorism focused on the relationship between an individual's environment (stimulus), their behavior (response, and the subsequent outcome of their behavior consequence). Specifically, for a behaviorist, learning occurs when past experiences (stimulus-response-outcome) increase or decrease the frequency of future behaviors, specifically, when positive behavioral outcomes lead to increases in behavioral frequency (e.g., when a veterinary student answers a question in class and is correct or gets praised, the frequency of their question answering behavior is likely to increase), while negative behavioral outcomes lead to decreases in behavioral frequency (e.g., when a veterinary student studies for a quiz in a noisy café instead of at home where it is quiet and performs poorly, the frequency of their café-studying behavior is likely to decrease). This stimulus–response conditioning is seen as deterministic, that is, the environment causes this change in frequency through the consequences of the response, and not that the individual is *choosing* to engage (more or less) in a particular behavior. For more in-depth discussion about behaviorism, revisit Chapter 2.

In the middle of the twentieth century, through the work of Julian Rotter and, later, Albert Bandura, **social learning theory** emerged. Initially, this work was viewed as an extension of behaviorism but later evolved into an alternative to behaviorism. Rotter proposed "social learning," a theory that involved individuals developing subjective interpretations and values of experiences that then led to expectations for future performance. Specifically, according to Rotter (1954, 1966), individuals developed expectancies based on the relationship between their past behaviors and subsequent outcomes. These behavior–outcome expectancies would then result in an increase in the potential of the individual to engage in that specific behavior if the outcome was previously positive, or a decrease in the potential to engage in that specific behavior if the outcome was previously negative. While this relationship may sound behavioristic – positive behavioral outcomes lead to an increase in the frequency of the behavior – the cause of the relationship had shifted from the environment to the person. It is the individual's psychological beliefs (expectancies) that cause the potential increase (or decrease) in the frequency of the behavior, not the existence of factors present in the environment (stimuli).

In addition to these general behavior–outcome expectancies, an individual engaged in a behavior was also influenced by the individual's perceived locus of control (Rotter 1966). That is, whether the individual believed they were in control of their own success or failure due to their own skills and actions (internal control), or if success or failure was out of their control and due to luck, chance, or others' actions (external control). Thus, from Rotter's social learning theory perspective, engaging in specific actions was influenced by perceptions of previous success or failure (expectancies), as well as whether the individual believed that they were able to cause those successes or failures (locus of control).

Part 1: Human Agency

Rotter's social learning theory served as a bridge between the stimulus–response relationships of behaviorism and the learning–performance relationships of cognitivism. Albert Bandura crossed this bridge, expanding and extending social learning theory in the 1970s, and proposing a new, albeit related, **social cognitive theory** (Bandura 1971, 1986, 1997; Bandura and Cervone 2023). Bandura's social cognitive theory of human learning rests on the concept of *emergent interactive agency* (Bandura 2001a). As explained by Bandura, emergent interactive agency means that humans have control or intentionality when it comes to their own actions (agency), these actions exist within and between individual and social systems (interactive), and, over time, the exercise of this control leads to self-development and adaptation (emergent), thus, "agency refers to acts done intentionally" (p. 7).

Agency itself is the ability of an individual to exhibit control over themselves and their environment: "To be an agent is to influence intentionally one's functioning and life circumstances . . . people are self-organizing, proactive, self-regulating, and self-reflecting" (Bandura 2006, p. 164). Bandura's human agency stands in contrast to the determinist behaviorist view where life is a function under environmental control. It is the intentional nature of agency, with its focus on the regulation and control of one's cognition, behavior, and motivation, which leads to humans playing a functional role in the conduct of their lives.

When Bandura refers to agency, he typically is referring to personal agency, although he defines three types of agency (Bandura 2001a, 2006): personal, proxy, and collective. *Personal agency* represents an individual's ability to influence the course of their own action and environment. Through their own cognitive, behavioral, social, and affective choices, individuals are able to exercise control over the quality and direction of their life. That said, there are times when one would like to move their life in a direction over which they have little direct control. In these cases, an individual may engage in *proxy agency*, where one is able to influence others to act on their own behalf. This socially mediated form of agency relies on others who have the power, resources, and means to assist in the achievement of the individual's desired outcomes. Finally, one may be motivated to impact both their own lives and the lives of others through *collective agency*. In collective agency, goals are achieved only through the socially interdependent efforts of multiple people. These are not a group of randomly acting individuals, but rather, the coordinated and conjoint efforts of individuals who share intentions, knowledge, and skills in the pursuit of common goals.

Part 2: Human Agency and Self-Regulation

Bandura (1986), created a contextual model within which emergent interactive agency exists. For Bandura (2001b), human functioning involves the integration of individual, social, and environmental factors, a codetermination of development, adaptation, and change. Thus, individuals are influenced by their own thoughts and the actions of others, as well as contributing to their social sphere that may in-turn impact others as well.

Bandura called his model, at various times, reciprocal determinism, triadic codetermination theory, and reciprocal causation. **Reciprocal causation** emphasizes the interactional nature of personal, environmental, and behavioral factors on learning and behavior (see Figure 3.1). Specifically, *personal factors* include the learner's physical characteristics (e.g., height, weight, eye color), cognitive characteristics (e.g., knowledge, beliefs, self-efficacy), and social/cultural characteristics (e.g., group membership, social reputation, cultural roles), while *environmental factors* include a situation's physical context characteristics (e.g., building attributes, climate), social context characteristics (e.g., group size, others' attitudes), and response characteristics (e.g., positive outcomes, negative outcomes), and *behavioral factors* include an individual's actions (e.g., performance, habits), expressions (e.g., emotions, demeanor), and verbalization (e.g., explanations, exclamations).

Bandura proposed that the relationships between the three factors – personal, environmental, and behavioral – were bidirectional, although personal factors were seen as having primacy, with external influences affecting

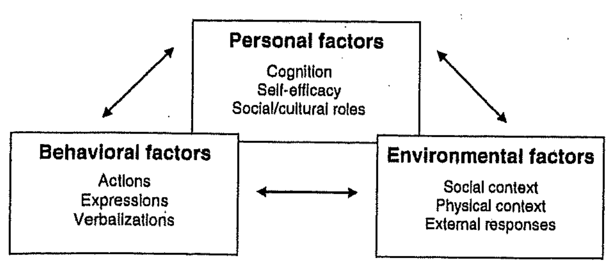


Figure 3.1 Bandura's reciprocal causation and the interaction between personal, environmental, and behavioral factors.

thought and behavior indirectly as the internal factors determine the meaning, importance, and lasting impact of the external influences. Thus, given the interactive nature of reciprocal causation, the proximal causes of one's action depend on the salience and synthesis of the personal, environmental, and behavioral factors: "In human transactions, one cannot speak of 'environment,' 'behavior,' and 'outcomes' as though they were fundamentally different events with distinct features inherent in them" (Bandura 2006, p. 165).

For example, consider Chris, a veterinary student, who volunteers at a small animal veterinary clinic and enjoys interacting with the clients in the clinic. This enjoyment (a personal factor) leads Chris to volunteer in the clinic more often (a behavioral factor), which leads to Chris feeling more confident at the clinic (a personal factor), which leads to Chris being provided additional opportunities within the clinic by the attending veterinarians (an environmental factor) which leads to Chris exhibiting more leadership (a behavioral factor), and so on. Also, consider Dr. Perez, who is discussing risk factors for the progression of renal disease within a class using PowerPoint slides (a behavioral factor) to a group of students (environmental factor). Dr. Perez notices students squinting as they attempt to read the slide's small font and view the slide's small images (an environmental factor), so Dr. Perez makes a mental note (a personal factor) and revises her slides, enlarging the font sizes and images, prior to the next class (a behavioral factor). In both examples, Chris and Dr. Perez are evidencing control (agency) over their lives, choosing to work in the clinic and revising the slides, respectively.

A. Fostering Agency Through Self-Regulation

For Bandura (1986, 2001a, 2018), personal agency is a product of a broad self-regulatory framework. Agency presupposes that individuals have proactive control over their thoughts and actions. This control is governed by the recurring processes of developing expectations, setting challenging goals, and mobilizing one's resources, skills, and knowledge in pursuit of these goals. It is the discrepancy between one's expectations, as expressed in goals, and one's current state, as determined through self-reflection, that motivates one to action. This self-regulatory framework involves four aspects: intentionality, forethought, self-reactiveness, and self-reflectiveness.

1) *Intentionality*. Agency presupposes that humans can self-generate plans to enact future courses of action. Intentionality refers to an individual rationally (as opposed to impulsively) designing and proactively committing oneself to a course of action through *goal setting*. Developing these goals for action involves merging one's desires, values, and strengths with mentally visualizing the possibility of future actions and outcomes. At the planning stage, it is impossible to know the ultimate outcomes of a plan enacted. Individual agency only extends to planning and enacting, as outcomes are beyond one's direct causality. Although, once a plan is enacted, an individual may interpret the outcomes and intentionally reengage with the planning process, a form of self-guidance and self-motivation managed by forethought.
2) *Forethought*. Forethought involves looking ahead in time to consider which courses of action may lead to beneficial outcomes and which to detrimental outcomes. These *outcome expectations* are the amalgam of past experiences resulting in success and failure, current conditions of resources and priorities, and personal efficacy beliefs related to the likelihood of future success or failure (i.e., projected reciprocal causation). This forethought, which may project 10 minutes or 10 years into the future, motivates an individual to move beyond the present, to escape the forces that may be influencing their current behavior, and to intentionally choose and enact a path forward.
3) *Self-Reactiveness*. Although intentionality and forethought may result in a well-defined and highly motivated course of action, influenced by mentally projecting possibilities for success or failure into the future, success is not guaranteed. The benefits of actions are due in part to ongoing self-reactiveness, particularly self-regulation involving consistent and on-going monitoring and evaluation of the current state and progress of one's actions, in relation to one's desired outcomes and personal standards. This self-evaluation provides information upon which to self-regulate one's plans and actions, as well as to sustain internal motivation to act, in continued pursuit of positive outcomes. Thus, agency is a continuous process of self-regulation guided by one's reflective self-consciousness (self-reflectiveness).
4) *Self-Reflectiveness*. While self-reactiveness and self-regulation provide real-time course-of-action correction, self-reflectiveness provides a higher level of self-evaluation focused on long-term, life-scale issues of one's motivations, values, and pursuits. To what degree are one's current life pursuits still valid and aligned with one's values? To what degree is one making progress toward a long-term goal? Overall, are one's collective courses of action being successful in moving one forward? A core aspect of this self-reflective agency is the judgment of one's efficacy in impacting change. This *self-efficacy* belief system, belief in one's ability to successfully engage in specific actions that will yield predictable and positive outcomes, is central to planning, refining, sustaining, and completing a course of action.

> Among the mechanisms of personal agency, none is more central or pervasive than people's beliefs in their capability to exercise some measure of control over their own functioning and over environmental events. Efficacy beliefs are the foundation of human agency. Unless people believe they can produce desired results and forestall detrimental ones by their actions, they have little incentive to act or to persevere in the face of difficulties. (Bandura 2001a, p. 1)

Ultimately, self-reflectiveness focuses on an individual's agency in directing the course of one's life.

It should be noted that while listed sequentially, the human agency core features of intentionality, forethought, self-reactiveness, and self-reflectiveness are not linear, but rather integrated in an ongoing lived experience where processing impacts learning. For example, consider a veterinary student with an upcoming equine reproduction test. In demonstrating agency, the student reflects on their past successes and failures related to studying for tests (self-reflectiveness) and develops a plan likely to succeed for their upcoming test studying (intentionality, forethought). The student recognizes that studying in loud, social spaces has been detrimental to their test performance in the past and that studying in a quiet, solitary environment has typically led to success (self-reflectiveness). Therefore, the student elects to study in a small alcove in the library to increase their chances of a successful study session (forethought), as would be evidenced by a successful test performance. In addition, the student recognizes that it would be helpful to bring their course textbook, lecture notes, and computer to support their studying (forethought), as well as water and bananas as they intend to study for several hours, and thirst and hunger have interrupted their study plans previously (forethought, self-reflectiveness). The student gathers their resources, including sustenance, and locates an out-of-the-way alcove in which to study. After a short period of study, the student notices that they are being distracted by a small group of students working on a group project nearby, so they pack up their belongings and find a new quiet, solitary location (self-reactiveness). In addition, as the student continues to study, they recognize that there are concepts and terms in the textbook that are not in their notes and that they do not fully understand (self-reactiveness). To remedy the situation, the student decides to open their computer and search for additional information on the web (intentionality, forethought), a strategy that has been successful in the past so the student believes it will be successful now (self-reflectiveness) to enhance their understanding (self-reactiveness). Over the next several hours, the student monitors their comprehension to identify gaps in their understanding (self-reactiveness), reflects on strategies that have been helpful for comprehension in the past (self-reflectiveness), devises a new plan to close these comprehension gaps (intentionality, forethought), and enacts that plan. Throughout the study session, the student's self-efficacy for study strategy use will be enhanced when the strategy use facilitates their understanding and diminished when the strategy use does not facilitate their understanding. Ultimately, through this expression of agency, a positive outcome of the study session would be an excellent test performance. Through self-reflectiveness, this positive outcome would likely lead to increased self-efficacy for studying. Thus, intentionality, forethought, self-reactiveness, and self-reflectiveness are intertwined to provide individuals with the agency needed to guide their lives and pursue their interests based, to a large extent, on their efficacy beliefs – their beliefs that they *can* have a positive impact on their own lives.

Part 3: Human Agency and Self-Efficacy

Bandura's concept of agency is intimately related to efficacy beliefs. Personal **self-efficacy** relates to reflections that yield judgments as to one's ability to successfully accomplish a future task. The importance of personal self-efficacy in agency is that self-efficacy provides motivation for an individual to engage in actions they believe will have positive outcomes: "To be an agent is to intentionally produce certain effects by one's actions" (Bandura 2018, p. 130). The belief that one is capable of successfully engaging in actions provides the impetus to regulate one's behavior and persist in the face of challenges, thus representing a core belief of agency.

> Efficacy beliefs influence whether people think self-enhancingly or self-debilitatingly, optimistically or pessimistically; what courses of action they choose to pursue; the goals they set for themselves and their commitment to them; how much effort they put forth in given endeavors; the outcomes they expect their efforts to produce; how long they persevere in the face of obstacles; their resilience to adversity; how much stress and depression they experience in coping with taxing environmental demands; and the accomplishments they realize. (Bandura 2001b, p. 270)

One recurrent question regarding personal self-efficacy is whether self-efficacy is a general trait ("It is easy for me to focus on my goals") or a specific belief ("I can successfully complete a feline ovariohysterectomy"). Bandura (2018) is clear on this point: "Perceived self-efficacy is not a global trait, but a differentiated set of self-beliefs linked to distinct realms of functioning" (p. 133). Indeed, there are robust findings (see Goetze and Driver 2022; Klassen and Tze 2014; Livinţi et al. 2021) that higher self-efficacy is related to higher performance in a vast array of specific activities (e.g., exercising, teaching, writing, reading), academic domains (e.g., math, science, medicine, engineering), and academic management (e.g., academic self-regulation, academic motivation, academic self-control, academic judgments), as well as negatively related to specific affect (e.g., mood, depression, anxiety, fear). Therefore, one should think specifically; that is, "self-efficacy for ______." For example, self-efficacy for presenting at conferences, self-efficacy for writing research reports, and self-efficacy for veterinary surgery. The degree to which one specifies depends on the domain, thus self-efficacy for veterinary surgery may better be specified as self-efficacy for orthopedic surgeries and self-efficacy for soft tissue surgeries.

However, there are several general trait self-efficacy measures (i.e., General Self-Efficacy Scale, Self-Efficacy Scale, New General Self-Efficacy Scale; see Scherbaum et al. 2006), and accompanying research examining the relationship between general self-efficacy and a variety of topics, including higher work resilience in veterinarians (McArthur et al. 2021), health care usage in older adults (Whitehall et al. 2021), and life satisfaction (Azizli et al. 2015). Finally, specificity may be functional, that is, while self-efficacy to learn animal anatomy and physiology, and self-efficacy to learn food animal medicine and surgery may be important, it may be equally or more important that one has a high self-efficacy for learning new knowledge. Therefore, is self-efficacy specific or general? It depends.

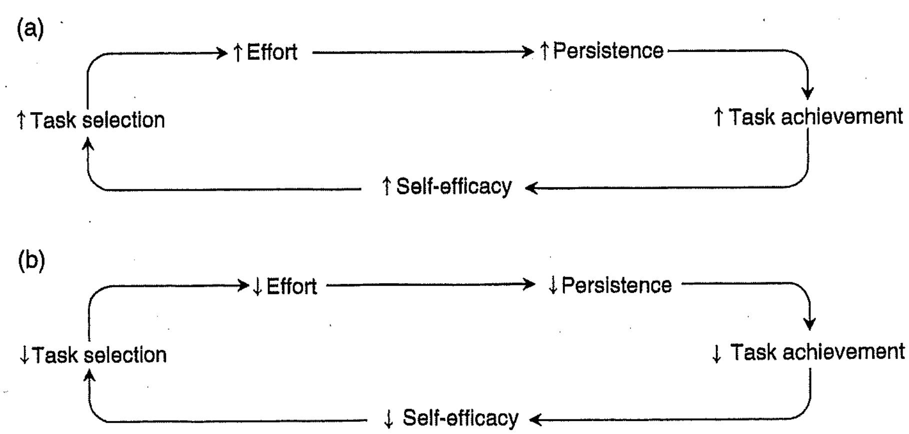
The last connection is that while personal agency is impacted by perceived personal self-efficacy, the aforementioned collective (group) agency is influenced by perceived collective efficacy. As groups of individuals work together to achieve a collective goal, they develop a shared, group-level, emergent collective efficacy beyond the sum of the group members' individual self-efficacies: "Members acting on their common beliefs contribute to the transitional dynamics that promote group attainments" (Bandura 2006, p. 166). The collective efficacy represents a shared belief in the group's ability to produce desired change or to achieve group goals. In addition, the quality of the shared collective efficacy positively impacts the quality of the group functioning (Gully et al. 2002; Salanova et al. 2020).

A. Impacts of Self-Efficacy on Action

The relationship between self-efficacy and specific actions has been demonstrated to have interesting impacts on behavior. Self-efficacy impacts not only which tasks are attempted, but also which tasks are completed and how much one learns (see Figure 3.2).

1) *Choices*. Individuals with high self-efficacy for a particular action will tend to choose to engage in that action more often than if they had low self-efficacy. That is, individuals will be more likely to choose activities that they believe will lead to success, rather than failure. In addition, if an individual both believes in the likelihood of their success *and* they value the outcomes of that success, they will be more likely to choose to engage in that action (Wigfield et al. 2016). For example, veterinary students may be more likely to participate in a voluntary rabbit dentistry wet lab if they have high self-efficacy for working with rabbits and/or dentistry and plan to pursue exotic medicine once in practice.
2) *Goals*. Individuals with high self-efficacy for a particular action will tend to set higher goals for the successful completion of that action. In addition, goals that are specific rather than general, short term rather than long term, and challenging rather than easy tend to foster

Figure 3.2 The cyclical nature of the (a) positive effects and (b) negative effects of self-efficacy on task selection, effort and persistence, and achievement.



greater motivation and engagement (Locke and Latham 2002, 2015). Further, goal setting and planning (forethought) help to focus an individual's attention and maintain that focus over time (i.e., commitment). This maintenance of attention leads to the self-evaluation of progress (self-reactiveness) which can have a positive impact on motivation from both perceived progress and perceived discrepancies between a goal and one's current outcomes, indicating a greater need for effort and persistence. For example, a veterinary student interested in behavioral medicine may volunteer with the local animal shelter's veterinarian to help with behavioral assessments and modifications. As this takes considerable time and effort, a student with high self-efficacy for the task may set goals to not only help numerous animals but also to design a long-term behavioral modification protocol the shelter can continue to utilize.

3) *Effort and persistence.* Individuals with high self-efficacy for a particular action will tend to put forth greater effort and greater persistence to be successful (Bandura 1997; Komarraju and Nadler 2013). This high self-efficacy includes high outcome expectations, beliefs that they *will be* successful (eventually), which leads to persistence in goals over time (achieving a series of short-term goals leading to the achievement of long-term goals). For example, a veterinary student with high self-efficacy who is interested in pursuing a career in Emergency and Critical Care may put forth effort by working through virtual cases to improve their level of knowledge and preparation regarding critical cases.
4) *Achievement.* Individuals with high self-efficacy for a particular action who set high goals, expend significant effort, and persist in that effort, tend to achieve more often than individuals with lower self-efficacy who expend less effort and are less persistent (Bandura 1977). In addition, the successful achievement of a desired action (goal) strengthens self-efficacy for the action itself, thus increasing the likelihood that the individual will attempt that action again in the future. For example, veterinary students with high levels of self-regulation tend to be more engaged in learning during their clinical clerkships and have higher performance levels (de Jong et al. 2017).

The relationship between these characteristics can be represented cyclically (see Figure 3.2). Specifically, an individual's high self-efficacy may lead an individual to attempt a task more often. In addition, while choosing the task more often, they are also likely to put forth significant effort and persistence to complete the task. Ultimately, this effort and persistence will tend to lead to achievement and an increase in task self-efficacy, which begins the process again (see Figure 3.2a). It should, however, be noted that the cyclical nature of self-efficacy can lead to detrimental effects, where poor self-efficacy leads an individual to select a task less often, put forth minimal effort and persistence, and, predictably, perform poorly (see Figure 3.2b).

B. Fostering Self-Efficacy

Given the cyclical nature of self-efficacy and achievement, and the causal nature of self-efficacy and agency, the development of self-efficacy is essential. Self-efficacy is positively impacted by several different types of experiences, each a different source of information from which an individual may make self-efficacy judgments. That said, it is not the experiences themselves that directly impact one's self-efficacy, rather it is an individual's interpretations of these experiences (Schunk and DiBenedetto 2020).

1) *Performance experiences.* The strongest indicator of future success and failure is past success and failure. These past performance experiences (sometimes referred to as mastery or enactive experiences) serve as the most reliable and authentic source of self-efficacy information – learning through the consequences of one's own actions. Still, judgments of "success" or "failure" may themselves come from several sources based on one's performance, including comparison to peers, progress over time, achievement of established criteria, and completion of tasks. Further, the nature of these judgments is important. For example, if a veterinary student successfully completes a physical examination, the impact that this success has on the student's self-efficacy for conducting physical exams will be influenced by how the student perceives the experience. If the exam is perceived as a routine canine wellness exam, the success may have minimal impact on their self-efficacy, but if the exam is perceived as a challenging diagnostic exam, their self-efficacy may be enhanced.

   In addition, as an individual progresses and overcomes challenges, based on effort and persistence, they may develop a **resilient self-efficacy**. Specifically, resilient self-efficacy is the ability, in the presence of difficulty and setback, to (i) maintain an expectation of success, (ii) monitor and reevaluate progress relative to desired outcomes, (iii) modify plans to account for the difficulties and setbacks as new courses of action emerge, (iv) maintain personal standards and criteria for success, and (v) reflect on the challenges, responses, and outcomes to accurately revise one's self-efficacy, as needed. Further, Djourova et al. (2020), indicate that resilient self-efficacy allows for the development of a sense of competence and control during uncertainty, and the ability to reframe challenges as learning experiences. As Bandura (1989) stated, "development of resilient self-efficacy requires some experience in mastering difficulties through perseverant effort" (p. 1179).

2) *Observational experiences.* In addition to experience, self-efficacy can be influenced through the observation of others' actions and their success or failure, sometimes referred to as vicarious experiences. Vicarious experiences include **vicarious reinforcement**, which involves individuals learning to exhibit a known behavior more often after observing another receiving reinforcement (i.e., a positive outcome) for the same behavior, while **vicarious punishment** involves individuals learning to exhibit a known behavior less often after observing another receiving punishment (i.e., a negative outcome) for the same behavior. Bandura (2018) refers to those observed as social models who may be physical, observed through face-to-face encounters, or symbolic, observed through social media or digital technologies, including textbooks. Thus, observing others' behaviors, attitudes, values, and resilience can lead to a change in self-efficacy, based on the positive or negative outcomes associated with the model's performance, without the presence of a direct performance experienced by the observer. This observation of others can serve to change one's motivation to act, standards for action, and self-regulatory capabilities through one's agency. In addition, it has been found that the nature of the modeling matters; individuals are more likely to be influenced by (i) a model who is perceived as similar in abilities, attributes, age, or gender; (ii) a model who is perceived as working hard to be successful, especially models who demonstrate resilience or who are observed when the observer is new to the task; and, (iii) multiple models being observed, rather than just one model (Bandura 1977; Gale et al. 2021; Schunk and Usher 2019). For example, if a veterinary student compares their successful castration of a cat to a (perceived) less skilled peer, the impact of their accomplishment on their self-efficacy for surgery is not likely to be significant; however, if their peer comparison is to a (perceived) highly skilled peer, the impact on their self-efficacy is more likely to be consequential.

   Finally, while traditionally an individual tended to interact with a limited number of other people in their day-to-day lives (e.g., family, friends, peers, colleagues), digital technologies have allowed individuals to observe others worldwide engaging in a vast array of behaviors 24 hours a day, including online education and tutorials, thus increasing an individual's potential observational experiences and repertoire of observed actions. Ultimately, while observations of others can influence one's self-efficacy, the impact of observed experiences on self-efficacy tends to be less than with performance experiences, and long-term changes in self-efficacy due to observation generally necessitate some performance experience at some point.

3) *Persuasive experiences.* Usually less impactful and shorter in duration than performance experiences and observational experiences, social persuasive experiences can also affect an individual's self-efficacy. Persuasive experiences include verbal communications (e.g., "excellent effort, try another approach, you'll get this") and behavioral communications (i.e., providing a student with an easier task when they are struggling with a more difficult task potentially communicates that the instructor believes the student is incapable of succeeding at the more challenging task). The impact of persuasive experiences is enhanced when the provider of the persuasion is perceived as credible and when the persuasion is provided frequently (Bandura 1977; Schunk and Usher 2019). Highly credible sources of performance information, such as experts, teachers, and successful peers, typically impact an individual's self-efficacy more than a less credible source and receiving credible messages more often tends to be more effective than less frequent persuasions. For example, a veterinary student may value feedback more from an experienced large animal veterinarian during the examination of a cow than from a veterinary student peer who is also just learning about bovine care.

   Also, individuals who are novices and lack a wealth of personal knowledge and experience may heed persuasive messages more than those with significant knowledge and experience. These novices may lack the personal knowledge and experience necessary to make their own judgments regarding their actions, so they may rely more on others' judgments, which may, in turn, impact their self-efficacy. Finally, two unfortunate caveats: negative messages tend to have more of an impact (reducing self-efficacy) than positive messages (increasing self-efficacy) and increases in self-efficacy due to persuasive experiences tend to fade if not verified through performance experiences.

4) *Physiological experiences.* A final source of information regarding one's self-efficacy is their own physiological and emotional reactions, such as excitement, calm, interest, fear, anxiety, and stress. These emotions may be interpreted as indicators of one's beliefs in their likelihood of being successful – "I'm nervous, I'm going to fail this test," or "I'm excited, this lab is going to be fun" – and, thus, increase or decrease one's related self-efficacy. For example, a veterinary student walking to an anatomy lab may feel restless and sweaty and perceive this as "anxiety" and an indication of being ill-prepared, resulting in a lower self-efficacy for completing the lab.

One emerging relationship regarding self-efficacy and physiological experience is the importance of the *interpretation* of one's physiological experience. Reexamining the veterinary student's experience of restlessness and sweating on the way to the anatomy lab, what if the student interpreted their physiological experience not as "anxiety," but rather, as "excitement," or if while they first interpreted the physiological experience as anxiety, they were subsequently able to reappraise the experience as excitement? This reinterpreting of one's physiological response is **cognitive reappraisal**. Cognitive reappraisal of the emotional interpretation of a physiological response or event (sometimes referred to as positive reappraisal) has been demonstrated to have a significant impact on subsequent thought and action (Gross 1998; Neta et al. 2022; Webb et al. 2012). Hanley et al. (2015) found that cognitive reappraisal following perceived academic failure was positively related to academic self-efficacy, in particular, the ability to reinterpret perceived failure as beneficial was associated with higher self-efficacy (i.e., resiliency). Similarly, Riepenhausen et al. (2022) determined that a disposition, or style, toward positive cognitive reappraisal – a tendency or bias toward interpreting or reinterpreting a negative physiological experience in a positive way – was associated with effective resilience. Finally, cognitive reappraisal is subject to its own self-efficacy: cognitive reappraisal self-efficacy is the belief in one's ability to successfully engage in cognitive reappraisal in order to regulate one's emotions (Goldin et al. 2009, 2012). Ultimately, cognitive reappraisal provides an avenue for the development of positive self-efficacy and resilience through the reinterpretation of negative physiological experiences.

C. Self-Efficacy in Academic Settings

Self-efficacy has a powerful impact on functioning within a classroom for both students and teachers. Previous discussions of the sources of self-efficacy (i.e., performance, observation, persuasion, and physiological experiences), impacts on behavior (i.e., choices, goals, effort, persistence, and achievement), as well as the development of agency (i.e., intentionality, forethought, self-reactiveness, and self-reflectiveness) all apply within the classroom.

1) *Student Academic Self-Efficacy*. Overall, high student academic self-efficacy, or the student's belief in their ability to successfully complete academic tasks and achieve academic goals, has a significant impact on the student's overall academic achievement. Academic self-efficacy has been posited as one of the most important factors in students' college success (Robbins et al. 2004). Specifically, higher student academic self-efficacy is associated with:

- increased academic learning, performance, achievement, and transfer;
- increased goal orientation, motivation, and self-regulation;
- increased commitment, effort, and persistence;
- increased problem-solving and self-regulation;
- increased domain-specific achievement (e.g., math, science, writing, and reading);
- increased use of cognitive, metacognitive, and deep processing strategies;
- decreased academic anxiety and stress; and
- decreased academic procrastination.

(Alemany-Arrebola et al. 2020; Bandura 1998; Hayat et al. 2020; Pintrich 2003; Schunk and DiBenedetto 2020; Walker and Greene 2009; Zimmerman and Kitsantas 2005).

2) *Teacher Self-Efficacy*. Similarly, high teaching self-efficacy, a teacher's belief in their ability to positively impact student learning performance, has a significant impact on teacher and student classroom learning performance. Specifically, higher teacher self-efficacy is associated with:

- increased teaching quality, engagement, commitment, and motivation;
- increased teaching enthusiasm, passion, resilience, and retention;
- increased quality of lesson plans, classroom management, assessments, and strategies;
- increased teacher cooperation with students, colleagues, and parents;
- increased student achievement, academic self-efficacy, motivation, and engagement;
- increased teaching satisfaction and well-being; and
- decreased teacher burnout and stress.

(Calkins et al. 2023; Kasalak and Dağyar 2020; Perera et al. 2019; Poulou et al. 2019; Tschannen-Moran et al. 1998; Tschannen-Moran and Woolfolk Hoy 2007; Wang et al. 2015).

The impact of teacher self-efficacy is substantial, resulting in more effective class preparation, teaching practices, student assessment, and, ultimately, student learning. The sources of teaching self-efficacy – performance, observational, persuasive, and physiological experiences – can be seen in the work of Gale et al. (2021), who surveyed and interviewed beginning, novice, and career teachers, with 1-year, 2–3 years, and 4+ years of secondary teaching experience, respectively. Gale et al. found that participants' teaching self-efficacy was most impacted by performance experiences and persuasion experiences, regardless of teaching experience level (beginning, novice, career). Teachers' performance experiences were based primarily on student achievement (e.g., test performance, classroom performance, "light bulb" moments); when students learned, teachers had a higher perception of their own teaching. In addition, teachers identified consistently low student learning and an inability to explain this lower student performance as the main source of information lowering their self-efficacy. Gale et al. also reported that more experienced teachers with high teaching self-efficacy were more likely to reappraise negative teaching experiences as opportunities to learn (resiliency). In relation to social persuasion, the teachers reported the importance of informal comments from administrators and other teachers and the need for persuasive comments to be paired with performance experiences. Finally, while observational experiences were expected to have a greater impact on teachers' self-efficacy, Gale et al. explained that teaching is often a solitary experience. Rarely do classroom teachers observe other teachers and rarely are classroom teachers observed themselves; thus, classroom teachers only infrequently have the opportunity to engage in observational experiences. The impact of affective or physiological experiences on self-efficacy was rarely mentioned by teachers.

3) *Calibration of Self-Efficacy Judgments.* Given the importance of self-efficacy in an individual's task engagement and achievement, it is reasonable to question whether individuals are accurate in estimating their ability to be successful and whether it might matter: Does a high self-efficacy inherently mean high task performance? **Self-efficacy calibration** is the relationship between a student's self-efficacy for a task and their ability to perform that task. For example, imagine a veterinary student learning to complete a canine otoscopic evaluation. If this student has high self-efficacy for performing otoscopy, but their performance is low, they would be overconfident (a self-efficacy that is unwarrantedly high), while if their self-efficacy is low and their performance was high, they would be underconfident (a self-efficacy that is unwarrantedly low), both evidencing a self-efficacy miscalibration.

Does it matter if self-efficacy and task performance are miscalibrated? Given the relationship between self-efficacy and agency, this miscalibration could have significant ramifications. For instance, an overconfident student may choose to engage in procedures for which they lack sufficient skills, neglect to prepare sufficiently for an upcoming procedure, rush or pay inadequate attention during the procedure, fail to seek help when needed, or injure the patient. An underconfident student may spend too much time preparing for the procedure and neglect other important tasks, exude apprehension that is interpreted by the client as a lack of skill, accept inappropriate advice from less-skilled others, or choose not to engage in procedures and thus, diminish their skills (Boekaerts and Rozendaal 2010; Schunk and Pajares 2004; Usher 2009; Zvacek et al. 2015).

Talsma et al. (2019, 2020), examined academic self-efficacy and performance across two studies in which undergraduate psychology students rated their self-efficacy for course-based written assignments and multiple-choice content exams, as well as their self-efficacy for their course performance (i.e., course grade). In addition, Talsma et al. collected students' performance on the written assignments, multiple-choice exams, and course grades. Across both studies, Talsma et al. found that while overall academic self-efficacy was positively related to academic performance, on an individual level, academic self-efficacy and performance were often miscalibrated. Specifically, at the task level, concerning self-efficacy and performance related to written assignments and multiple-choice tests, students tended to be underconfident; that is, their expressed self-efficacy was lower than the assignment/exam performance. However, at the domain level, concerning course grades, students tended to be overconfident; that is, their expressed self-efficacy was higher than their course grades. Finally, across both studies, lower-achieving students tended to be overconfident regarding both written assignments and exams, while high-achieving students tended to be underconfident (Talsma et al. 2019), or appropriately confident (Talsma et al. 2020).

Given these findings, care needs to be taken in interpreting self-efficacy and performance results. Does it matter if self-efficacy and task performance are miscalibrated? It depends. First, the general findings that task self-efficacy and task performance are positively related are based on correlations and should not be interpreted as causal. That is, having a high self-efficacy for a particular task does not directly cause high task performance or indicate definite higher performance. A student can have high self-efficacy and low performance, as well as low self-efficacy and high performance; therefore, general measures of self-efficacy are not enough. It is important to consider the self-efficacy of individual students related to specific tasks. Second, the accuracy of self-efficacy ratings seems to be positively related to experience; therefore, less experienced students should be expected to overrate their performance, while more experienced students should be expected to more appropriately rate their performance.

Part 4: Human Agency and Social Modeling

Social cognitive theory's emphasis on self-regulatory human agency is grounded in the interactions between the individual, the social, and the environment (reciprocal causation), including one's cognition and expectancy beliefs (self-efficacy), and one's interactions with others (social modeling). Social modeling involves learning by observing others and the consequence of their behaviors, where learning can be a new behavior, an increase or decrease in the frequency of a known behavior, or a modification of a known behavior, and where "behavior" may be physical, cognitive, social, or affective. Social modeling provides an avenue of learning that is distinct from the more traditional approach of learning through direct experience (Bandura 2001a, 2006). This observational learning through social models is a source of human agency that simplifies the learning process, allowing for the learning of one's culture – language, behaviors, mores, ideology, and ethics – through social interaction, not formal instruction, and where "culture" may be one's local culture (e.g., family, social club, veterinary clinic) or global culture (e.g., ethnicity, region, country).

Social modeling provides a mechanism for the link between everyday social experiences and cognitive, behavioral, social, and affective functioning. Individuals can learn both formal and informal knowledge, skills, and attitudes through the cognitive processing of social models. For example, a veterinary student can learn informally about animals and veterinary medicine by watching the animals and veterinarians engaging in everyday actions. The student can also learn when engaging in more formal actions, as part of a class or laboratory session. When a veterinarian models procedures as part of a class, they are explicitly articulating what they are doing, why, and the expected outcomes. A benefit of learning through social modeling, rather than direct experience, lies in the access to social models. Where once one needed to be in the presence of a model, one now merely needs to access their smart phone or laptop.

In recent years, the availability of social models has exploded. Traditionally, social models were limited to those present in one's everyday face-to-face experiences, for example, one's parents, siblings, extended family, friends, school peers, work colleagues, and daily acquaintances (e.g., a barista, car mechanic, office assistant, convenience store clerk). Today, however, one has access to models from across the globe, anytime day or night, via the internet. With a few clicks, one can observe the newest social craze being modeled in fashion, reading, pottery, politics, cooking, music, sports, and entertainment, as well as veterinary practice, surgeries, and pharmacology. This global reach of social models can lead to the development of new properties of agency as these models demonstrate emerging, unfamiliar, or infrequently experienced attitudes, values, behaviors, language, and resilience. In addition to socially experiencing these new properties, one is often able to see the outcomes of the knowledge and skills. Observing behaviors and outcomes, and constructing new outcome expectancies, can lead to increases or decreases in one's self-efficacy for the new knowledge and skills. In turn, these new outcome expectancies influence one's motivation, goals, plans, actions, reactions, and reflections – an individual's agency (i.e., intentionality, forethought, self-reactiveness, self-reflectiveness).

A. Characteristics of Effective Social Models

The role of the social model is not always well defined but is often simply an individual doing what they do on a daily basis: parents parenting, teachers teaching, and workers working. That said, there are characteristics that have been identified that make for a more effective model (Bandura 1971, 1986). It is, however, important to understand that these characteristics are perceptions of the observer and not objective attributes of the social model. The effectiveness of a social model depends on perceived:

1) *Competence*. An effective model is perceived by the observer to be competent in the behavior they are modeling. For example, a veterinary student may find a well-published veterinarian conducting antimicrobial resistance research highly competent as a researcher and worth emulating, but a class peer conducting a lab experiment as a less competent researcher and less likely to be emulated.
2) *Prestige and power*. An effective model is perceived by the observer to have power and prestige, in the form of status, respect, influence, reputation, resources, and/or authority. For example, a first-year veterinary student may find a fourth-year veterinary student who has published a paper and received a job offer as reflecting prestige and power and, thus, worthy of emulation.
3) *Socially Acceptable Behavior*. An effective model is perceived by the observe to be engaging in socially or culturally acceptable (often referred to as stereotypical) behaviors. For example, a veterinary student is more likely to mimic veterinary behaviors (e.g., social interactions, dress codes, conflict management) that are deemed more typical of veterinarians.
4) *Relevance*. An effective model is perceived by the observer to be exhibiting behaviors that have some functional value or relevance to the observer or the observer's situation. For example, a veterinary student interested in pursuing a residency in small animal internal medicine is more likely to find a small animal internist worthy of emulation than a public health veterinarian.

B. Observational Learning from Social Models

The process of observational learning through social models involves the interaction between one's social experiences and cognitive functions. Bandura (2001b), identified four cognitive functions, or methods of processing, necessary for effective observational learning: attention, retention, production, and motivation.

1) *Attention.* The first criterion for effective observational learning is that the observer's attention must be focused on the model and the behaviors of importance in which the model is engaging. In addition, this attention needs to be focused on the relevant task features of the performance. The focus of the observer's attention may be influenced by both the actions of the model, such as verbalizations ("See how the dog's leg moves through the full range of motion") and operations (the instructor demonstrates moving the dog's leg through a full range of motion repeatedly), as well as the mindset of the observer, such as prior knowledge and skills (growing up, the student had a pet dog who had hip dysplasia and thus lost much of his range of motion), and value preferences (fostering ethics of care).
2) *Retention.* The observer must encode the model's behaviors, verbally and/or visually, in memory. Memory retention is intricately related to attention in that one's focus of attention influences what and how one learns. In addition, as with attention, retention is influenced by the actions of the model, such as how the model aligns what they are saying with what they are doing, and the processing by the observer, such as how the observer connects new observations to prior knowledge. For example, veterinary students performing their first live animal surgeries might be asked about the methods they used to remember how to perform the procedure once they were standing at the operating table (Langebæk et al. 2015). In this case, the majority of students were able to remember the steps needed by recalling the surgical demonstration videos that were provided by the instructor. Instruction such as assigned reading, lectures, and practicing foundational surgical skills on models or cadavers did not align the instruction to the action as effectively as the demonstration video of a model performing the procedure in its entirety. The students were then able to connect their new observations (their first live animal surgery) to their prior knowledge (the memory of the steps performed in the video). Ultimately, retention is a function of what and how the observer processes the social model – what we process we learn.
3) *Production.* The production of the observed behavior is an essential aspect of observational learning; indeed, it is the reproduction of the observed action that indicates what the observer has learned. However, the observer's first reproductive attempts may be error-prone or simple approximations of the observed behavior; thus, reproducing the observed behavior immediately may help the observer to learn the behavior (the behavioral movement being an additional form of processing) and may allow the model to provide corrective feedback to the observer. For example, Thomson et al. (2019), found that when learning to perform dental extractions, students found the laboratory setting (where they could practice the hands-on skillsets) to be more valuable than lecture time, perceiving that their technical skills development improved most because the instructional setting allowed for immediate feedback and involvement from instructors. However, it may be the case where the observer is simply unable to replicate the observed behavior due to a lack of knowledge or skill. In addition, there are situations where the observer does not attempt to replicate the observed behavior for days, weeks, or years later due to the lack of need to do so.
4) *Motivation.* Finally, while an individual may have attended to, mentally retained, and be capable of exhibiting a new behavior, they may still not engage in the behavior if they are not motivated to act. This is particularly relevant given that veterinary students often struggle to maintain high motivation levels over the course of their studies (Mikkonen and Ruohoniemi 2011). The observer must *want* to perform the modeled behavior. An individual is more likely to be motivated to perform a new action if (i) they have observed others, such as role models or successful classmates, engaging in the action reaping positive consequences; (ii) they see the value of engaging in the new behavior as contributing to or an indication of the achievement of their goals, such as veterinary students maintaining their motivation to study when they deem the course content to be useful in obtaining their future goals (Parkinson et al. 2006); (iii) they view engaging in the new behavior as a challenge that will increase their self-efficacy, specifically, a difficult but attainable challenge, that with effort and persistence will result in success, and (iv) they perceive the new behavior as evidence of or contributing to their membership in a particular group, as indicated by the large number of national and international student clubs and organizations focused on specialties and interests that offer experiential learning opportunities available outside of the veterinary curriculum. Ultimately, Dale et al. (2010) determined that veterinary students with a preference for complexity, or a deep approach to learning, tend to have higher intrinsic, social, and extrinsic motivation.

Part 5: Human Agency and Identity

Human agency, the ability to regulate one's cognitive, behavioral, social, and affective processes in pursuit of individual, social, or environmental change, is built upon intentional self-regulation, efficacy beliefs, and social learning. This human agency also synergistically supports the construction of one's **identity**. Identity, as a self-theory, can be viewed as both a product and process and comprise both individual and social influences (Bandura 2006; Berzonsky 2011; Berzonsky and Kuk 2021; Crocetti et al. 2022). As a *product*, identity is a persistent cognitive structure that provides an *individualized frame of reference* for representing and interpreting past and present experiences, choices, beliefs, and values, as well as projecting these to plan for the future. As a *process*, identity functions to organize and understand one's experiences and identity-relevant information and to motivate and self-regulate one's socio-cognitive strategies to construct, maintain, and revise one's individualized frame of reference. In addition, the experiences, choices, beliefs, and values that give rise to one's identity may have either an individual or social genesis – the interpretation of one's experiences and the influence of one's social groups.

Identity, like agency, is an on-going process of self-regulation through (i) evaluating one's past, present, and future experiences, (ii) consciously and intentionally making life path decisions and commitments, (iii) constructing a sense of control of one's life, and (iv) continuously evaluating one's functioning to strengthen effective actions and beliefs, weaken ineffective actions and beliefs, and initiate change and adaptation as needed. Bandura (2006) explicitly links identity and agency: "As an agent, one creates identity connections over time and construes oneself as a continuing person over different periods of one's life" (p. 170). Similarly, as stated by Berzonsky (2011), from the identity side of the conversation: "Having the cognitive resources to represent the past, and then use transformations of those representations to anticipate the future, enables people to transcend time and maintain a sense of themselves as persistent volitional agents who think, doubt, will, act, desire, and self-regulate" (p. 56). Thus, the development of agency and self-regulation help an individual to construct an identity.

This relationship between identity and agency is embedded in three main identity-processing styles as proffered by Berzonsky: informational identity-processing style, normative identity-processing style, and diffuse-avoidant identity-processing style (Berzonsky 2011; Berzonsky and Luyckx 2008; Berzonsky and Kuk 2021; Crocetti et al. 2022). These identity styles are based on effective (or ineffective) agency and self-regulation, giving rise to effective (or ineffective) identity construction: "Selfhood embodies one's physical and psychosocial makeup, with a personal identity and agentic capabilities operating in concert" (Bandura 2006, p. 170).

1) *Informational identity-processing style.* Individuals with an informational identity-processing style are rational, self-directed, decision focused, and open minded to new ideas and new experiences. They are also flexible in their approach to how they see themselves, as evidenced by well-developed self-reflection and self-awareness, a questioning of their own self-beliefs, and a willingness to entertain values and ideas distinct from their own. The sense of identity of individuals with an informational style tends to represent personal values, beliefs, and goals derived from deliberate self-reflection and self-knowledge (i.e., agency). In general, an informational identity-processing style is associated with a more positive identity construction, including adaptive and problem-focused coping, effective decision-making strategies, and mastery achievement goals.
2) *Normative identity-processing style.* Individuals with a normative identity-processing style are (i) rational, but intuitively so, eschewing the need for engaged cognition; (ii) committed to their ideals, but through premature cognitive closure, unquestioningly adopting the ideals of others; (iii) conscientious and self-disciplined, but unwilling to entertain values and ideas different from their own; and (iv) dedicated to existing structures, but intolerant of ambiguity and changes in the status quo. The sense of identity of individuals with a normative style tends to represent a firm and unquestioning adoption of the collective identities of others, such as a family; a religious, cultural, occupational, or political organization; or specific self-attributes, such as patriotism, inclusivity, or athleticism. In general, a normative identity-processing style is associated with positive and negative identity construction. Specifically, a normative style is positively associated with goal setting, engagement, conscientiousness, and achievement goals, but negatively associated with open-mindedness, tolerance for ambiguity, and need for deliberate cognitive engagement.
3) *Diffuse-avoidant identity-processing style.* Individuals with a diffuse-avoidant identity-processing style attempt to avoid making a conscious and rational choice of identity, seeking instead to procrastinate or vacillate based on the present circumstance or with whomever they are currently associating. When choices are made, they tend to be weak, reactive, hedonistic, and guided by situational demands and the avoidance of stress and conflict. In addition, those with a

diffuse-avoidant style tend to engage in minimal self-discipline and self-awareness and have low self-esteem and academic difficulties. The sense of identity of individuals with a diffuse-avoidant style tends to represent maladaptive coping and dysfunctional decision-making focused on self-satisfying with choices related to furthering one's popularity, reputation, or distinction. In general, a diffuse-avoidant identity-processing style is associated negatively with identity construction, including poor cognition, adaptation, coping, and decision-making.

The overlap between identity and agency is substantial: "As the model of triadic reciprocal causation suggests, a sense of selfhood is the product of a complex interplay of personal construal processes and the social reality in which one lives" (Bandura 2006, p. 170). Berzonsky (2003), Schwartz et al. (2005), and Berzonsky and Kuk (2021) found that agency and self-regulation were positively associated with informational and normative identity-processing styles and negatively associated with a diffuse-avoidant identity-processing style. In addition, Berzonsky and Kuk established that agency and self-regulation mediate the relationship between informational style and depression and loneliness for first-year students, such that information style is positively related to agency and self-regulation, which are negatively related to depression and loneliness. Ultimately, one's identity is at least partially a function of one's agency – poor agency negatively impacts one's identity construction.

A. Personal Identity and Veterinary Medicine

These relationships between identity, agency, and self-regulation are important as one considers the construction of veterinary medical students' professional identities as veterinarians, and also practicing veterinarians' identities as teaching veterinarians. First, it is important to clarify that there is not a single "veterinary identity" or "veterinary educator identity." The identities of a veterinary surgeon and a veterinary epidemiologist and a livestock veterinarian are likely to overlap, yet also differentiate. In addition, each individual has more than a single identity, potentially, including a personal identity, professional identity, cultural identity, and religious identity, to name but a few. Finally, identities are not static, but rather evolve and adapt as one's experiences, values, behaviors, and contexts change, for example, as one's professional life develops from veterinary student to novice veterinarian to experienced veterinarian, or one's job focus changes from clinical practice to academic practice (Armitage-Chan 2020; Armitage-Chan and May 2019; Gardner and Hini 2006).

The construction of a strong and appropriate veterinary identity is essential to the vocational success, career satisfaction, and mental health of the veterinarian. According to Armitage-Chan and May (2019), the development of veterinary identity has three main phases. The initial phase accounts for the development of a naïve self, as one moves from being a college student to a veterinary student. As a college student, the individual will have little or no first-hand experience with veterinary medicine, so their identity is based on conjecture, rather than the exploration of veterinary experiences. As veterinary students engage in their veterinary studies (the second phase), they will experience a multitude of situations and experiences, including exposure to new knowledge and skills, as well as to practicing veterinarians, animals, clients, surgeries, and contexts. Within these situations, the students will experience the integration of self, actions, and environments (Bandura's reciprocal causation) leading to the development of beliefs and values through the necessity of veterinary interpretations and choices. This second phase may extend into a student's early career as they navigate their new professional work environments. While working as a veterinarian (the third phase), individuals become fully responsible for enacting their role as a veterinarian, interpreting their environment, making choices, acting in accordance, and bearing the responsibility for those actions (mental and physical). During this third phase, veterinarians reflect on the development of their identity, determining the alignment between their identity (as represented by their values, choices, and actions) and their environment (the vocational and social pressures inherent in their work). Ultimately, it is the interplay of these individual and social influences, contexts, and processes that lead to professional identity construction, maintenance, and ongoing development.

The result of veterinary identity construction, as depicted by Armitage-Chan and May (2019), may be any of Berzonsky's three identity-processing styles. Although, as mentioned by Armitage-Chan and May, identity construction is "complex and messy" (p. 160), more complex and messier than three phases and three outcomes; however, these phases and outcomes provide a foundation for understanding the challenges that can be faced by new veterinarians and new veterinary educators. A misalignment between one's identity and one's environment, when one's environmentally induced actions do not align with one's values and beliefs (identity dissonance), may lead to poor mental health and job dissatisfaction, increased fatigue and burnout, and decreased resilience (Armitage-Chan 2020; Fawcett and Mullan 2018). This misalignment may be the result of perceived failure in properly supporting an animal's care, differing judgments from colleagues in animal care, lack of instrumentation necessary to complete needed treatments, reduction in animal care due to restricted client finances, and criticisms from clients regarding empathy and care (Armitage-Chan and May 2019; Armitage-Chan 2020; Mossop and Cobb 2013). In the case of misalignment, the solution is frequently an adjustment in one's identity or the pursuit of a new environment.

Fostering a stable identity requires a significant degree of agency, based on an ongoing integration of self-regulation and self-efficacy. Within veterinary education, professional identity construction is recognized essential to the development of fully functioning veterinarians (Armitage-Chan 2020; Mossop and Cobb 2013). The intentional development of a professional identity within veterinary education entails explicit discussions and modeling regarding professionalism, as well as designing opportunities for students to consciously reflect on their experiences, beliefs, choices, and outcomes with the intent of exploring and committing to a sense of identity as a veterinarian. Thus, the combined development of identity and agency involves (i) intentionally planning and committing to goals based on one's values, beliefs, and knowledge, and one's forethought regarding potential outcome expectancies, (ii) deliberately engaging in one's plans, monitoring one's progress in relation to those plans, and making adjustments, as needed, and (iii) reflecting on the overall process (beliefs, goals, actions, outcomes) and creating a deliberate and rational guiding sense of self.

Part 6: Educational Implications of Social Cognitive Theory

Social cognitive theory is a robust and wide-ranging theory addressing learning in an integrated context of the individual and the social. This reciprocal causation is the ether within which the individual processes their experiences and develops their agency and identity. Social cognitive theory is not a narrow, specialized theory with limited application; rather, it is an everyday theory of human functioning, including functioning within the realm of veterinary medical education. The application of social cognitive theory constructs to veterinary medical education are innumerable. What follows are a few implications of social cognitive theory for the classroom, clinic, and lab.

A. Human Agency and Self-Regulation

1) *Students' learning involves the integration of their thoughts and actions, as well as the people and environments around them.* While learning results from processing, that processing may take several forms, including cognitive, behavioral, social, and affective processing. Students may learn cognitively through experiences diagnosing patients, studying class notes and scholarly articles, and making informed decisions; behaviorally through completing procedures, using diagnostic equipment, and emulating veterinary specialists; socially through observing veterinarians, discussing issues with peers, and answering client questions; and, affectively through monitoring and reflecting on their emotional responses, developing and reevaluating their beliefs, and reappraising the cognitive labels they apply to new and prior emotions and experiences. This processing is integrated within a student's individual, social, and environmental experiences (reciprocal causation); thus, a veterinary student's learning environment needs to include deliberately integrated individual, social, and environmental experiences and reflections.
2) *Students' learning is enhanced when they are given opportunities to develop and demonstrate control over their learning and lives.* As students learn through their integrated individual, social, and environmental experiences, they need to develop a sense of agency. This agency is built on the self-regulation of intentionality, forethought, self-reactiveness, and self-reflectiveness. Further, self-regulation is guided by a student's self-efficacy, their belief in their ability to successfully act. Thus, veterinary students need to be given opportunities to self-regulate: to plan, act, succeed, fail, revise, act, succeed, fail, and, ultimately, to self-reflect and self-evaluate, leading to changes in their agency, self-regulation, and self-efficacy, as well as, potentially, their identity.

B. Human Agency and Self-Efficacy

1) *Students' learning is guided and sustained by efficacy beliefs.* Due to the importance of self-efficacy in relation to one's agency, it is important that individuals become aware of its existence and its impacts on their behavior. A greater understanding of self-efficacy beliefs and their influence on one's self-regulation can lead to greater planning, regulating, and performing, and, ultimately, success. Self-efficacy beliefs are the result of a synthesis of informational sources: experience, observation, persuasion, and physiology. Specific information from multiple sources regarding the effectiveness of one's planning, regulating, and performing can lead to more accurate judgments, as well as a better understanding of the need for regulation. Ultimately, healthy self-efficacy beliefs can lead to greater resilience. Thus, veterinary students need to be given authentic and challenging tasks to complete and then receive support in

task completion and accurate feedback on their task performance.

2) *Students' learning is strengthened by focusing on resilience and small successes.* In working on authentic and challenging tasks, some tasks will inevitably lead to unsuccessful task completion. In the face of struggle, two avenues may appear: reduce the difficulty of the situation or raise and maintain one's efforts and expectations for success. Reducing the level of challenge to achieve success is less likely to lead to long-term growth than developing resilience by reevaluating one's expectancies, developing new plans, engaging in greater or redirected effort, and evaluating one's progress continuously. Bandura (1993) emphasized that expectations must remain appropriate and that self-efficacy should be built through intermediate goals. The key to impacting change in self-efficacy, based on the cyclical nature of self-efficacy (see Figure 3.2), is to foster small, but meaningful, achievements. Small achievements may be more attainable than large-scale achievements, nudging one's self-efficacy in a positive direction incrementally. Thus, veterinary students need to be engaged with tasks of varying degrees of difficulty to strengthen known and new knowledge and skills, and to develop the resilience necessary to maintain effort and persistence when challenged, until the task is completed.

3) *Students' learning is aided by the reappraisal of the sources of self-efficacy information.* Engaging in authentic and challenging tasks will tend to lead to various emotional states that are evaluated and labeled – exhilaration, anxiety, joy, stress, triumph, and frustration – which, in turn, may impact one's task performance, and, ultimately, one's self-efficacy. The labels that a student uses to identify an emotion are not automatic and beyond the student's control; thus, veterinary students should be encouraged to reexamine and reevaluate their emotional responses and labels in order to foster greater resilience and self-efficacy.

C. Human Agency and Social Modeling

1) *Students' learning is expanded through the observation of social models.* Learning is not attained simply through first-hand experience, but can also be the result of observational experience. Observing others (models) engaging in actions and the results of those actions (positive or negative) can lead to the development of new actions in the observer. These new actions, however, may not be reproduced immediately, but rather, potentially after a delay from days to months to years, depending on the need or motivation of the observer to engage in those new actions. In addition, these models may be in the observer's immediate environment, or they may be virtual, available online. Thus, veterinary students can be taught not only through direct instruction and problem-solving but through the observation of others engaging in relevant actions.

2) *Students' learning is generated through the cognitive processing of social models.* Observational learning is the result of distinct cognitive processes. Specifically, the observer must focus their attention on an appropriate task and the components of that task, as well as retain the nature, components, and procedures for completing that task. In addition, the observer must be physically able to complete the observed task and be motivated to do so. Thus, veterinary students must not only be provided with appropriate models and the modeling of relevant actions but also be encouraged to cognitively process their observations in the moment to better retain and reproduce them later.

3) *Students' learning is supported by the use of competent, relevant, and resilient social models.* An important component of observational learning is the attributes of those observed. Models are most effective when they are perceived by the observer to be competent in the observed task, socially powerful and prestigious, engaged in socially acceptable behaviors, and relevant to the observer's needs and desires. In addition, in the pursuit of developing resilient students, students can learn resiliency by watching models who struggle, persist, and eventually overcome challenges to be successful. Thus, it is important that veterinary students observe novice, resilient, and expert models whose actions align with their level of knowledge and skill and are relevant to their specific goals and actions.

D. Human Agency and Identity

1) *Students' learning is focused through the development of agency and identity.* Identity provides students with a personal frame of reference for understanding and engaging with themselves and the world around them. Identity is constructed through one's agency – guiding, enacting, interpreting, and reflecting on their own individual and social experiences – leading to the creation and commitment of their own beliefs, values, and actions. A conscious, self-regulated, and flexible identity and agency provide a student with the motivation and vision necessary to guide their own learning path and progress. Thus, veterinary students need to be provided with cognitive, social, behavioral and affective opportunities to develop and execute their agency and self-regulation in order to construct and strengthen their identities.

2) *Students' identity is made conscious through identity-focused curriculum and self-reflection.* The construction of identity is fostered when students consciously align their beliefs and values to the development of their own actions and then reflect on the outcomes and self-satisfaction of those actions. In addition, student identity construction is bolstered from watching others' actions and comparing those actions with their own beliefs and values in order to reflectively examine their relationship. Comparing one's own and others' beliefs and values with actions and outcomes can lead to the development of a conscious, self-regulated, and flexible identity. Thus, veterinary students need a curriculum that provides observational moments where beliefs and values intersect with actions, along with explicit opportunities for students to reflect on their own beliefs, values, and actions.

Social cognitive theory provides a foundation for how people synthesize their individual and social experiences in attempting to construct more adaptive ways of acting and being. Through the self-regulation of one's cognitive, behavioral, social, and affective actions, an individual reflects on who they are, and where they are, in creating a plan for moving forward. As one moves forward, they reflect on their goals and progress in order to have a better understanding of their development. This self-awareness and self-reflection provide information for the review and revision of their goals and actions, as well as a better understanding of their capabilities. Ultimately, how students process their individual and social experiences determines what they learn and who they become, which leads to the importance of processing in learning, memory, and cognition.

Section 3: Learning, Memory, and Cognition

The pursuit of understanding learning, memory, and cognition is a quest to balance the structure and function of the brain with the structure and function of the individual. What is the relation between one's experience, thinking, and action (cognitive, behavioral, social, and affective)? Mayer (1992) discussed three views of learning and instruction that can help to organize the following discussion: Learning as Response Acquisition, Learning as Knowledge Acquisition, and Learning as Knowledge Construction.

Learning as Response Acquisition focuses on the development of appropriate behaviors as a result of positive consequences for appropriate behaviors (or approximately appropriate behaviors) and negative consequences for inappropriate behaviors – what behaviorism refers to as shaping. In this model, the learner responds, and the teacher provides feedback. Learning as Knowledge Acquisition and Learning as Knowledge Construction are more like Part 1 and Part 2 of the same view, rather than separate views. This knowledge acquisition and construction view emphasizes the roles of memory and cognition in the processing of experience and the development of understanding.

Part 1: A Framework for Memory and Cognition

For decades, discussions of learning, memory, and cognition have been based on a model of **information processing** provided by Atkinson and Shiffrin (1968) that is neat and tidy. The problem, however, is that learning, memory, and cognition are neither inherently neat nor tidy. The Atkinson and Shiffrin *dual-store model* provides a framework, or an organization, for examining learning and performance. What follows is a discussion that uses the dual-store model for organizational purposes but goes beyond the original model with ideas and concepts developed since the model's inception (see Figure 3.3).

Imagine a veterinary student sitting in an animal nutrition lecture. Their lecture experience begins through the **stimulation** of their five senses – seeing (the room, the instructor), hearing (the instructor, other students), touching (their computer, their phone), smelling (the room, the banana in their backpack), and tasting (their gum, the top of the pen they are chewing on) – with these stimulations briefly occupying their **sensory memory** (sometime referred to as sensory store or sensory register). Unfortunately, their senses and brain cannot adequately process all the stimulation they are experiencing, so

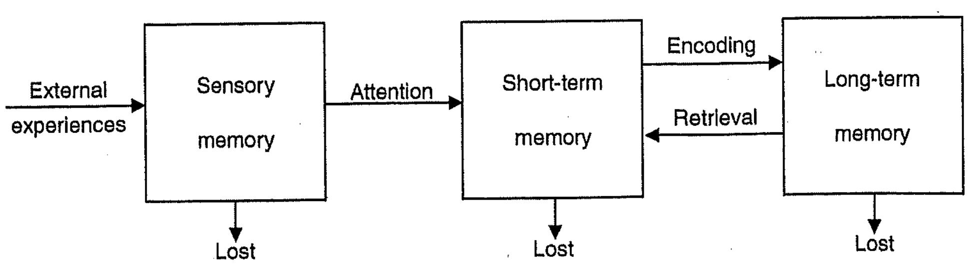


Figure 3.3 A simplified representation of Atkinson and Shiffrin's (1968) dual-store model.

through **attention** the student narrows their field of experience to just a few items, perhaps what the instructor is saying and the computer on which they are typing. The items to which the student is now paying attention enter a form of **short-term memory** – what the instructor has said, the meaning they have constructed from the instructor's words, and what the student is typing – and exist only for a short amount of time. Unfortunately, the student's brain can only maintain the contents of its short-term memory for a very brief period of time. The student must pay attention to what the instructor has said long enough to create meaning and write the ideas down, using their computer. If the student is able to pay enough attention to what the instructor has said, perhaps relating the instructor-expressed concepts to their previous experiences, as well as typing the ideas into their computer, the student may **encode** the ideas discussed by the instructor into **long-term memory**. The student may then **retrieve** these long-term memories, at a later time, to solve a problem, answer a question, or make meaning from new experiences.

As mentioned previously, the Atkinson and Shiffrin model may look neat and tidy, but each aspect of the model is complicated, iterative, cyclical, and integrated. In addition, the processing of information is fragile and subject to interference, leakage, and forgetting. Thus, while the dual-store model appears to have distinct boundaries between sensory memory, short-term memory, and long-term memory the boundaries are overlapping, imprecise and porous. In addition, as will be seen, human information processing is a tale of limited processing resources, where limited processing leads to significant information and knowledge loss and requires distinct strategies to navigate the limits.

There have been several revisions to the Atkinson and Shiffrin model over the intervening years (see Figure 3.4). With regard to sensory memory, originally posited as a very brief retention of sensory information in the form it was first experienced (i.e., visual stimulation retained in a visual format), the concept of sensory memory now includes the influence of existing meanings on how sensations are first perceived, and greater understanding of the relationship between sense receptors and brain function. In addition, one aspect of the model that has undergone significant revision since it was first proposed is the role and nature of short-term memory. Initially, short-term memory was considered an aspect of cognition where a small amount of information or experience was stored or actively maintained for a short period of time (Cowan 2008), and comprised of sensory-specific stores (e.g., visual, auditory, linguistic). That is, short-term memory was considered to have primarily a storage role in cognition, with some limited rehearsal, search, and retrieval processes. Since the model's publication, the role of short-term memory has been subsumed within the larger construct or working memory, which entails a larger role of processing, rather than an emphasis on the storage of a small amount of information or experience. Finally, as proposed by Atkinson and Shiffrin, long-term memory was concerned with the encoding of new information, searching for that information at a later date, and, subsequently, retrieving that information. In this approach, learning was a function of mental rehearsal (more time rehearsing information equals more learning), and forgetting was a function of interference and decay (less interference at learning equals more retention). At present, the methods of encoding have been expanded significantly beyond rehearsal, the organization of knowledge has been recognized as an essential aspect of long-term memory, the relationship between encoding and retrieval has been emphasized, and the role of context in learning and memory has been highlighted. These changes, and others, necessitate an augmented model to facilitate the model's representation of cognition and to provide a better foundation for its use in providing organizational structure to a discussion of learning, memory, and cognition.

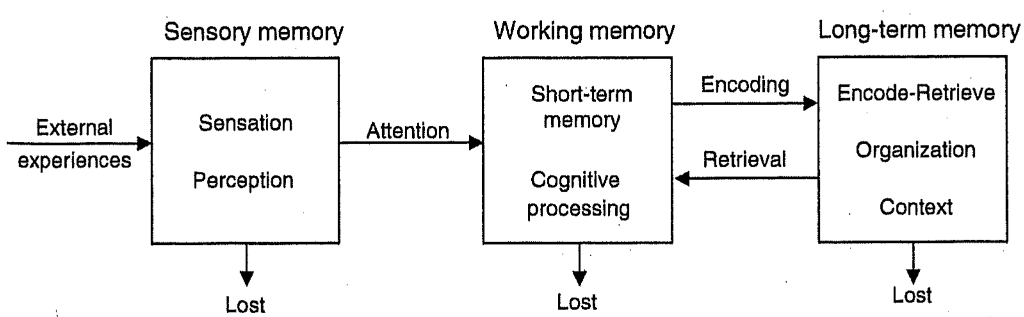


Figure 3.4 A modification of Atkinson and Shiffrin's (1968) dual-store model emphasizing newer theorizing and empirical findings related to learning and memory.

A. Sensory Memory: Sensation and Perception

The first element of the revised learning and memory model is **sensory memory**, comprising sensation and perception (Yorzinski and Whitham 2023). **Sensation** involves the stimulation of any or all of an individual's sense receptors. As a veterinary student examines a cow's eye in a laboratory setting, their visual photoreceptors (rods and cones) will be stimulated by the light reflecting from the cow's eye, their auditory receptors (organ of Corti hair cells) will be stimulated by the sound waves emanating from their lab partner's mouth, their touch receptors (mechanoreceptors) will be stimulated by the cow's eye coming in contact with their fingers, their olfactory receptors (chemoreceptors) will be stimulated by the preservation chemicals wafting in the air and entering their nose, and their taste receptors (taste receptor cells) may be stimulated by the gum they are chewing. These stimulations, from the potentially millions of receptors stimulated, are transduced into neural signals that are then processed by the brain in specialized locations for each sense (e.g., primary visual cortex, primary auditory cortex). This initial sensory processing has a large capacity but a short duration. That is, the veterinary student will experience a multitude of simultaneous and continuous sensations from their environment, but each only briefly, with each sensation typically available for additional processing for less than a second, depending on the sense. This rapid attenuation of sensations is often due to interference where new sensations replace existing sensations, or decay in a simple fading of the original sensation). These sensations will then be further processed by the brain through perception.

This process of **perception** involves recognizing and interpreting raw sensations. For example, in looking at a canine brain metencephalon transection (a raw visual sensation), where does the pyramidal tract end and the trapezoid body begin (i.e., object recognition)? A perception is influenced by both the sensation itself (bottom-up information) and the veterinary student's context, experience, knowledge, and expectations (top-down information). If a student is looking across a field at several horses – four with dark coats and one with a light coat – the light-colored horse is likely to be more noticeable (bottom-up information) as it stands out more (it is distinctive), however, if one of the dark-colored horses is owned and cared for by the student, that horse will be more noticeable (top-down information) as it is more emotionally salient. That said, the degree to which conscious, cognitive processing (e.g., choices, beliefs, motivations) influences perception is uncertain (Cermeño-Aínsa 2020; Stokes et al. 2013). For example, was the student's fondness for their horse a function of the perception itself (i.e., occurring in the primary visual cortex), or was that fondness determined at a higher level of cognition, where the horse perception was mapped to prior knowledge (i.e., prefrontal cortex) and affect (i.e., insular cortex). While the exact nature of how perceptions begin their quest for meaning is unclear, what is clear is that perception requires sensorial interpretations by the brain and that the brain's capacity to sense is far greater than its capacity to perceive and process.

B. Attention: Narrowing of the Field

While sensory memory (sensation and perception) helps to facilitate an individual's interaction with the world around them, the individual is not at the mercy of an autonomously functioning brain, focusing only on shiny objects and meaningful content. Humans have the ability to influence, or self-regulate, what they perceive through attention. **Attention** is a series of processes that allow an individual to select, modify, and sustain a mental focus on various aspects of their external and internal worlds (Narhi-Martinez et al. 2023). The capacity of this focus, however, is limited and leads to two central questions: How many things can we attend to? How long can we attend to them? The exact numbers are not particularly important, although the short answers are (i) beyond a singular point of focus attention becomes less than full on any one of the foci, and (ii) the duration may be a few seconds or much longer during vigilant attention, although the quality of the attention degrades with time. In short, perhaps better answers are "only a few" and "only for a short time." In addition, attention's capacity and duration also depend on the individual, varying from person to person and situation to situation. That said, while the specifics are at least a bit uncertain, the concept that attention has a limited capacity and duration is exceptionally important. Attention represents the first aspect of cognition where limited processing is an issue.

A key function of attention is selection. Relative to selection, *external attention* guides one's focus toward aspects of the world around us, while *internal attention* guides one's focus toward specific cognitive processes and knowledge (van Ede and Nobre, 2023). In addition, *voluntary attention* is under at least partial control of the individual, guided by prior knowledge, values, and emotions, while reflexive or *involuntary attention* is captured as a result of a particularly salient stimulus. These salient stimuli may involve attributes of greater magnitude (e.g., loud noises, noxious odors, fast-moving objects), increased novelty (e.g., unusual smells, unique tastes, odd images), considerable social relevance (e.g., noticing a long line waiting to hear a speaker, people smiling at a newborn animal, reading a book because it is on the best sellers list), or elevated personal meaning (e.g., seeing one's own cat, smelling one's favorite food, hearing one's best friend's voice). A quick note that just as perception may be bottom-up or top-down, so may attention (Leber and Egeth 2006); specifically, a veterinary student may examine an animal's eyes due to their conscious conclusion that the animal's eyes may provide diagnostic information (bottom-up) or due to eye examination being a standard component of a routine physical examination (top-down).

Ultimately, in relation to Atkinson and Shiffrin's model, focusing one's attention on an aspect of the world or the mind makes it more likely that the subject of that attention is moved into working memory and available for further cognitive processing. Of the vast array of stimuli available through sensory memory, most of it is lost as it is never attended to and therefore is either replaced by the next set of sensations, or fades with time.

C. Working Memory: Storage and Processing

As an individual attends to external stimuli and internal processes, these stimuli and processes become resources for **working memory**. For example, if a veterinary student is studying the function of a sheep's heart using a textbook, they are simultaneously engaging several resources: (i) maintaining in memory the purpose of the studying (the form and function of a sheep's heart), (ii) actively examining the material being studied (the text and images in the textbook), (iii) retrieving and maintaining in memory the knowledge already known from previous biology classes (the form and function of a human heart), (iv) processing of the textbook material and prior knowledge to create new knowledge (how the human and sheep hearts are similar and different), and (v) retrieving from and encoding to long-term memory (retrieving prior knowledge of the human heart or sheep's anatomy and physiology, as needed, and encoding new knowledge of the sheep's heart). In addition, and perhaps most importantly, (vi) the student is controlling their attention to manage their resources. Specifically, completing the study effectively involves the ability to actively maintain in memory the textbook information and long-term prior knowledge, while processing the information to construct new understandings and retrieving additional prior knowledge, and storing newly constructed knowledge while suppressing potential distractions (e.g., overheard conversations or the bright sunny day outside the window, internal irrelevant thoughts of lunch or other work to be completed). The engagement of these cognitive resources through *attentional control* occurs in and through working memory, involving significant storing and processing of knowledge. Ultimately, Pavlov and Kotchoubey (2020) have demonstrated that individual differences in working memory capacity (the individual's ability to leverage their working memory resources) are based primarily in differences related to an individual's working memory attentional control and *not* differences in short-term storage capacity.

Miyake and Shah (1999, p. 450), define working memory as "those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition, including novel as well as familiar, skilled tasks." Thus, working memory involves an integrated effort of various ***executive control** functions* including the focus, control, and maintenance of attention; the maintenance, manipulation, and updating of long-term memory; and the inhibition of attention and long-term memory activation (Miyake and Shah 1999). Neurologically, these functions are distributed broadly across the prefrontal cortex, the anterior cingulate cortex, and the parietal cortex, as well as related perceptual sites (i.e., Broca and Wernicke's areas); thus, working memory is not a specific place or space, but a collection of functions and structures.

Perhaps the most defining feature of working memory, as with attention, is its limited capacity and limited duration. The number of resources that can be consistently brought to bear on a situation is small and the duration short, without continued attention (Cowan 2010; Halford et al. 2007). The estimates of working memory capacity vary from three or four items to eight or nine items, depending on the balance of attention, storage, and processing, as well as new versus prior knowledge, with the duration of items ranging from 10–30 seconds (or more), depending on the maintenance of attention and the presence of distraction (Brady et al. 2016; Broadbent 1975; Cowan 2001; Miller 1956). Specifically, if items in working memory are only attended to briefly, they remain in working memory briefly, but if they are attended to for a longer duration, they will stay in working memory for a longer duration. In addition, distraction, the presence of additional information in working memory from either the mind or the environment, may lead to the shifting of attention and the subsequent loss of working memory resources.

1) *Working Memory Capacity*. Working memory capacity is the ability of an individual to engage efficiently in the attention, storage, and processing functions necessary for working memory to operate effectively (i.e., executive control, attentional control, and memory maintenance). In general, higher working memory capacity is related to higher memory performance – primary memory maintenance, secondary memory search, attentional control, resistance to interference, and long-term memory activation – and higher task performance – reasoning, lecture note-taking, multimedia learning, storytelling, and reading and language comprehension (Conway et al. 2002; Just and Carpenter 1992; Kane et al. 2001; Kiewra and Benton 1988; Lusk et al. 2009; Unsworth and Engle 2007).

Given working memory capacity's role in efficient and effective cognition (bigger is better), can working memory capacity be increased? Yes and no (mostly no).

Working memory training examines the impact of memory training on near and far transfer, where near transfer includes improvement to tasks that are similar to the training task (i.e., Does training on verbal working memory improve verbal short-term memory?) and far transfer is improvement on tasks that are dissimilar to the training task (i.e., Does training on verbal working memory improve reasoning?). Typical results from working memory training studies, across several meta-analyses, include small near-transfer effects and no far-transfer effects (Melby-Lervåg et al. 2016; Sala and Gobet 2017; Soveri et al. 2018; Teixeira-Santos et al. 2019). That is, individuals who engage in working memory training generally get better at the tasks upon which they are trained, but that training does not transfer to a different task. These results indicate that working memory training *does not* improve one's working memory, but rather, reflects a general practice effect where practice leads to specific improvements in the skills practiced.

2) *Cognitive Load Theory*. Cognitive load theory is based on the inherent limitations of working memory capacity and how these capacity limits interact with the instructional process (Sweller 1988; Sweller et al. 2019; Warren and Donnon 2013). Specifically, cognitive load theory posits that each task engaged in by an individual requires a series of cognitive resources in order to complete the task successfully (i.e., attention, storage, long-term memory, and processing requirements). These cognitive resource requirements place a "load" on the memory system and when this load is significantly high, it can negatively impact the learning and performance of the individual. In addition, this cognitive load involves the interaction between the task, the individual, and the environment, and yields two broad categories of load: intrinsic cognitive load and extraneous cognitive load.

Intrinsic cognitive load relates to the essential cognitive resources necessary to complete the task. For example, the task of a veterinary student listening to a cat's heart sounds might generally be interpreted as a lower intrinsic load task (see Figure 3.5a) as it requires minimal cognitive resources: proper placement of the stethoscope, listening to the heart sounds, and interpreting the heart sounds. A higher intrinsic load task may involve a veterinary student interpreting a serum biochemistry panel (see Figure 3.5b) where the student would need to understand the rationale for the panel, the metabolic functions of the liver, the parameters reported, and the parameters' reference values and ranges, as well as how these parameters and animal presentation interrelate. While Figure 3.5a and b indicate that both the heart sound and panel interpretation tasks are within the veterinary student's working memory capacity limits, there may be times when simply completing a task exceeds a student's working memory capacity limits due to the complexity of the task itself (see Figure 3.5c), leading to decreased performance and learning. For example, interpreting a serum biochemistry panel may be a low-load task for an experienced veterinarian, but may induce overload in a novice veterinary student. In this case, the student's performance will be limited, not by a lack of knowledge or external interference, but by an inability to marshal the necessary cognitive resources.

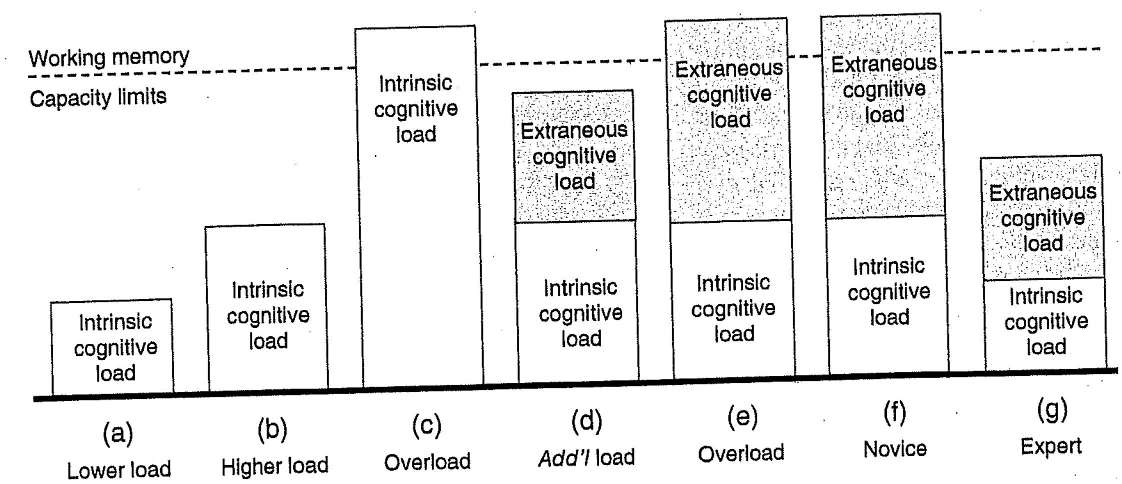


Figure 3.5 Intrinsic and extrinsic cognitive load interact with an individual's working memory capacity, as well as their long-term memory and expertise to influence performance: examples would include (a) a lower intrinsic load task, (b) a higher intrinsic load task, (c) a task where intrinsic load leads to an overload of working memory capacity limits, (d) a task that contains both intrinsic and extrinsic load, (e) a task where the intrinsic and extrinsic loads lead to an overload of working memory capacity limits, (f) a typical intrinsic and extrinsic load of a novice, and (g) a typical intrinsic and extrinsic load of an expert.

Extraneous cognitive load refers to cognitive demands in a situation, presentation, or instruction that negatively impact the individuals' ability to complete the given task. These extraneous cognitive demands are beyond the intrinsic cognitive load required to complete the task itself (see Figure 3.5d), meaning that these extraneous demands are in addition to the intrinsic demands. For example, if the veterinary student's serum biochemistry panel does not include normal or reference ranges for each parameter, the difficulty in interpreting the panel would rise artificially ("artificial" in the sense that a well-articulated panel that includes the normal or reference ranges would not result in extra cognitive load). In addition, if the interpretation was conducted under time duress or if some of the parameter values were unavailable, the difficulty of the task would be unduly increased. Finally, if the combined intrinsic and extraneous cognitive loads approach or exceed an individual's working memory capacity limits (see Figure 3.5e), task performance (learning, performance, and transfer) would likely be impeded.

While intrinsic and extraneous cognitive loads deal primarily with the task and the environment, respectively, cognitive load is also influenced by the individual (Szulewski et al. 2021). Novices, with little knowledge and experience (e.g., new veterinary students), are likely to have higher intrinsic cognitive loads and be more impacted by extraneous cognitive loads than experts with more well-developed and automated knowledge and experience (see Figure 3.5f and g). For example, in considering the serum biochemistry panel, intrinsic cognitive load will be lower for experts as their knowledge of liver function and panel information will be stronger and more easily accessible than a novice's, and the expert's cognitive procedures for interpreting the panel and interrelating the panel information with the animal's presentation will be less demanding (more automated) than a novice's. Finally, the expert is less likely to be distracted or impeded by extraneous cognitive loads (e.g., panel results that are visually hard to read, a hectic clinical environment, unclear animal presentation) than a novice.

3) *Baddeley's Multicomponent Theory of Working Memory.* Theoretically, perhaps the most well-developed model of working memory involves Baddeley's multicomponent model (Baddeley and Hitch 1974; Baddeley et al. 2021). Baddeley's model involves four basic components: the central executive, phonological loop, visuospatial sketchpad, and episodic buffer. The **central executive** controls working memory functions, including executive control, attentional control, and memory maintenance, as well as decision-making and planning. The central executive provides control over the rest of the working memory system (i.e., the phonological loop, visuospatial sketchpad, and episodic buffer). The **phonological loop** provides a brief (<2 seconds) and capacity limited (≈5 items) memory for verbal information, as well as the ability to extend this memory duration through the *articulatory rehearsal loop* that involves repeating verbal information in subvocalized speech (i.e., nonauditory inner speech). The **visuospatial sketchpad** serves a similar function as the phonological loop (including a limited capacity and duration) except for visual information. This visuospatial sketchpad allows an individual to connect one image to the next, providing a sense of continuity as one changes the focus of their gaze. Finally, the **episodic buffer** provides memory space for the integration of verbal and visual information and the encoding of information into long-term memory. Baddeley's working memory model has been extensively tested both behaviorally and neurologically, providing support for its viability, although gaps in its ability to explain the breadth of human behavior still remain (Baddeley et al. 2019; Logie et al. 2020).

In relation to Atkinson and Shiffrin's model, the theoretical concept of short-term memory has been expanded into working memory to include a far greater role for the control of attention, memory, and behavior (Baddeley et al. 2019). One essential aspect of working memory is the control and maintenance of long-term memory. The interaction between working memory and long-term memory is represented through the concepts of encoding, storage, and retrieval.

D. Long-Term Memory: Encoding, Storage, and Retrieval

The road to remembering is uncertain. As human beings, we sense a great deal in our environment, most of which is lost as we only attend to and perceive a small amount of what we sense. Of the small amount that we attend to and perceive, most of it is lost from our working memory as we use our limited working memory capacity to solve problems, engage with others, and make decisions. For some of our experiences, however, we manage to create memories of knowledge, skills, events, and experiences in long-term memory. When examining the relationship between working memory and long-term memory, we focus on encoding, storage, and retrieval.

1) *Memory Encoding.* Memory **encoding** is the process of transforming sensations into perceptions (sensory memory), perceptions into meaningful representations (working memory), and meaningful representations into stored knowledge, skills, and events (long-term memory).

Encoding is critical to creating useful long-term cognitive resources, including how well memories are stored, how long memories are retained, and how easily memories can be retrieved. Effective encoding can lead to strong and flexible memories, memories that are easily accessible and useful across a multitude of situations. Ineffective encoding can lead to weak and poorly connected memories that may fade quickly or become inaccessible. In addition, encoding may take different forms: semantic encoding (processing the meaning of experiences), visual encoding (processing the visual characteristics of experiences), auditory encoding (processing the auditory characteristics of experiences), and motoric encoding (processing the movement characteristics of experiences). There is also olfactory encoding (smell), tactile encoding (touch), and gustatory encoding (taste), although these have been less well-researched within cognitive science.

Whether one engages in effective or ineffective encoding often depends on the strategy used. Strategies designed to enhance the encoding of long-term memory may involve simple or complex approaches. For example, a simple approach to fostering encoding is the use of **chunking**. Given working memory's storage and processing limitations, it is helpful to have strategies that compact or compress information, making the information more efficient from a processing perspective. Chunking involves organizing smaller elements of information into larger, more meaningful units of information (Miller 1956; Norris and Kalm 2021). For example, "howarewefeelingtoday" comprise 20 elements (letters), where 20 elements fall well outside our working memory capacity and would be difficult to process efficiently. If one has knowledge of the English language, however, "howarewefeelingtoday" can be reorganized into "how are we feeling today." At this point, the 20 letters have been chunked into 5 words, which are easily managed by working memory. In addition, if "how are we feeling today?" is used repeatedly as one's greeting to friends and acquaintances, then it can become a onechunked unit of greeting, "how-are-we-feeling-today?," which would require even fewer cognitive resources to be used. An illustration would include a small animal neurologic examination, entailing the systematic evaluation of the entire central and peripheral nervous system. This can appear to be an overwhelming task for novice veterinary students. By chunking the examination into seven categories (mentation, posture and gait, cranial nerves, postural reactions, spinal reflexes, spinal palpation, and pain perception), experienced veterinarians can efficiently and effectively confirm the existence and localization of neurologic lesions.

It should be noted, however, that chunking is an inside-out process: the benefit of chunking depends on an individual's prior knowledge and not simply what one perceives. For example, while chunking "howarewefeelingtoday" into "how are we feeling today" would seem easy for an English language speaker, chunking "jaksiędzisiajczujemy" into "jak się dzisiaj czujemy" would be impossible unless one already knew Polish ("jak się dzisiaj czujemy" also means "how are we feeling today"). To create the word-based chunks, an individual must already know the words. Thus, when chunking information into meaningful units, the "meaning" aspect comes from within the individual and is not inherent in the experience. This is one of the reasons why more experienced veterinarians will encounter less cognitive load in most veterinary situations than novice veterinary students – more knowledge leads to more efficient chunking, which leads to more efficient processing. For example, an experienced veterinarian can efficiently localize a neurologic lesion during a physical examination appointment, whereas a veterinary student will likely need to consult their notes to recall each of the 12 cranial nerves and how to assess for neurologic deficits.

2) *Memory Storage*. Encoding experiences into long-term memory allows for the accumulation of vast amounts of information that needs to be interpreted, organized, synthesized, and integrated in order to be efficiently accessed and used. The distinction between information, knowledge, and memory is helpful in understanding memory storage and organization. **Information** refers to the fundamental facts and perceptions of experience that may lead to the development of knowledge. **Knowledge** refers to the construction of higher levels of meaning through the connection of new knowledge and experiences with prior knowledge and experiences (or the creation of new connections between existing prior knowledge), resulting in an individual's understanding of information to be developed into concepts and skills. Knowledge may be thought of broadly to include facts, concepts, and events (declarative knowledge); skills, behaviors, and procedures (procedural knowledge); and feelings, beliefs, and values (self-knowledge). In addition, the relationship between information and knowledge is iterative; specifically, new information may be processed into a higher level of meaning and thus become knowledge, yet this new knowledge may be considered information at a newer and more complex level, such that further processing may lead to an even greater understanding and thus a new level of more highly connected knowledge. **Memory** refers to the ability to encode, store, and retrieve information and knowledge, as well as the structures necessary to support these processes.

Thus, the concepts of information, knowledge, and memory are, by definition, interrelated. For example, consider a veterinary student attending an anatomy class where they first experience information, such as the basic facts and imagery of anatomy (e.g., direction terms, names, and forms of bones and muscles). This anatomical information becomes knowledge when it is processed – interpreted, organized, synthesized, and integrated – into a more meaningful form (e.g., skeletal and muscular systems, biomechanics). This new level of meaning can serve as necessary information for the development of more advanced meaning making (e.g., diagnosis, surgery, nutrition). A student's memory then serves to retain their developing information and knowledge for later retrieval and use in thought and action.

Memory itself, however, is not a singular concept, but rather, a collection of different memory systems and types (see Figure 3.6). Long-term memory can be seen as possessing two broad types of memory: explicit memory and implicit memory. **Explicit memory** refers to memory of which an individual is consciously aware and can readily and intentionally retrieve. Knowledge within explicit memory is typically referred to as declarative knowledge, or knowledge that can be declared. To illustrate, if a veterinary student was asked, "What are the four chambers of a dog's heart?," their reply would be declarative knowledge stored in explicit memory. **Implicit memory** refers to memory of which an individual is *not* consciously aware, and retrieval is nonconscious, occurring without the explicit intention of the individual. Since the knowledge, retrieval, and use are not conscious, the presence of implicit memories can be seen only through behaviors, not intentionally recollected. For example, an experienced veterinarian does not think back to their communication skills classes when consoling a grieving pet owner. They simply respond, using appropriate verbal and nonverbal communication techniques to offer an empathetic response. Finally, procedural knowledge may start as an explicit list of steps to be taken in the completion of a task (e.g., a wellness exam), but with practice, these steps will develop into procedural knowledge where the steps fade as a guide to action and the veterinarian simply moves from action to action without consciously recalling each explicitly.

3) *Explicit Memory*. Explicit memory, involving consciously and intentionally retrieved knowledge, is typically seen as comprising episodic memory and semantic memory. **Episodic memory** involves the remembrance of lived events and experiences (episodes) at specific times and places (Renoult et al. 2019; Rubin 2022). For example, a veterinary student may remember that yesterday they attended epidemiology class and sat in front of the classroom in a seat that made seeing the projection screen difficult. This student is remembering a specific event, not recalling a general conclusion that sitting in the front of the classroom makes seeing the projection screen difficult (i.e., semantic memory, see below). A specific form of episodic memory is *autobiographical memory*, which refers to the memory of lived events that have special meaning for the individual – these are the memories one uses when they describe their lives or their personal history. As such, autobiographical memories typically include high levels of meaning, emotions, and beliefs as part of the event description. Where were you when you found out that you were accepted into veterinary school? Over time, episodic memories tend to fade more quickly than autobiographical memories due to the enhanced meaningfulness of the autobiographical memories (Talarico et al. 2004).

In addition to episodic memory, explicit memory also includes **semantic memory** that involves memory for general knowledge, concepts, and facts that are *not* tied to specific events or experiences. Semantic memory focuses on the meaning of knowledge, concepts, and facts, where the meaning tends to be accumulated over time with repeated experiences. For example, a veterinary student who understands the structures and functions of the circulatory system will have constructed this knowledge through multiple interactions with the circulatory system (via lectures, readings, studying, and conversations), not at a specific time and place (e.g., Tuesday's lecture). In addition, this semantic memory

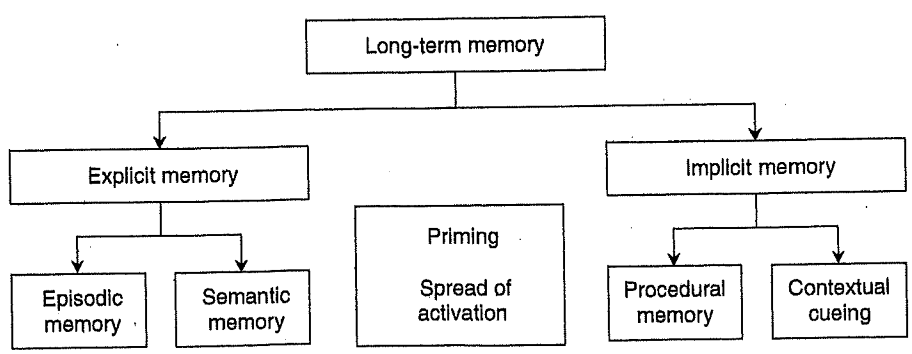


Figure 3.6 A classification of long-term memory components associated with explicit and implicit memory.

for knowledge, concepts, and facts tends to be organized into various structures or mental frameworks, including categories, networks, schemas, and concepts.

4) *Implicit Memory*. Implicit memory, involving nonconsciously and unintentionally retrieved knowledge, is typically seen as comprising procedural memory and contextual cueing. **Procedural memory**, or procedural learning, involves the learning of skills and habits, typically through extensive practice and experience, resulting in a degree of automaticity. As these skills and habits become more automatic, the individual possessing them begins to lose the ability to articulate what they are doing and why they are doing it. Nevertheless, the development of an automated skill always begins with the conduct of a conscious skill. For example, when a veterinary student first begins to learn how to tie a surgical knot at the beginning or end of a suture line, the experience is highly conscious, challenging, and less than successful; however, watching an experienced surgeon tie a surgical knot can be a bit of a blur. Developing a skill from conscious to automatic requires considerable practice. Early learning is typically slow, error-prone, highly attentional, and thus, more effortful (Anderson 1982; Fitts and Posner 1967). As a result of practice, performance may become more and more automatic such that the performance is faster, increasingly error-free, less attentional, and thus, less effortful. This increase in speed and accuracy is the result of the skill requiring fewer central cognitive resources (i.e., less attentional control, less decision-making), resulting in less cognitive load. While automaticity is generally considered a positive result of practice, developing automaticity can also lead to a lack of awareness and control (Charlton and Starkey 2011; Posner and Snyder 1975).

In addition to procedural learning, learning to use context cues to guide attention can also result in nonconscious and unintentional behavior (Sisk et al. 2019). **Contextual cueing** involves two components: the visual context and the behavioral action. For example, veterinary surgical personnel, after spending considerable time in a surgical suite, will develop a mental map of the visual space so that they nonconsciously know where all of the materials and equipment are located. This mental map will allow the surgical personnel to reach for needed materials or equipment without having to consciously scan or search the room in advance, thus reducing the attentional resources and cognitive load of the procedure itself. In the case of implicit contextual cueing, the awareness of the spatial layout becomes predictive, allowing the individual to unconsciously orient their attention to an appropriate location.

Beyond procedural learning and contextual cueing, priming and spread of activation can connect implicit and explicit memory. Both priming and spread of activation address how the activation of one piece of knowledge can lead unconsciously to the activation of a related piece of knowledge, making that knowledge more accessible and retrievable; thus, the process of activation occurs implicitly, while the knowledge that becomes activated may be explicit. In the case of **priming**, experiencing particular knowledge, such as concepts, thoughts, images, or emotions activates related knowledge, making that related knowledge more available for retrieval (McNamara 2005; Meyer and Schvaneveldt 1971). For example, a veterinary student may overhear a veterinarian talking about the nervous system. In the student's mind, knowledge related to the nervous system may become more active, such as concepts (e.g., neurons, neurotransmitters), images (e.g., an image of a dog's nervous system), or emotions (e.g., fear that they might be asked a question about the nervous system, a system for which their knowledge is uncertain). These concepts, images, or emotions may become more active implicitly, without the student's conscious awareness. Relatedly, **spread of activation** refers to how the activation of one piece of knowledge can unconsciously activate related knowledge, and that the newly activated knowledge can activate additional knowledge related to it (Collins and Loftus 1975; Fazio 2001). In this way, the knowledge activation spreads through a network of related knowledge (the more closely related two pieces of knowledge, the stronger the spread of activation). For example, the student who overhears the veterinarian's discussion of the nervous system may (nonconsciously) activate closely related conceptual knowledge (e.g., neurons, neurotransmitters), and that knowledge may activate further related concepts (e.g., axons, dendrites, synapses, receptors). These activations will make responding to subsequent questions regarding neurotransmitters or synapses easier.

5) *Memory Retrieval*. Memory **retrieval** is the process of accessing, activating, and transferring information stored in long-term memory into working memory for use. Memory retrieval is an uncertain process, as information stored in long-term memory is often partial or interpretive (i.e., not a video of events, or word-for-word transcriptions of discussions) and may involve weak or disorganized storage that results in incomplete or incorrect retrieval. Thus, what is retrieved depends on both the nature of the retrieval and on the strength and accuracy of the encoding. For example, a veterinary student may be examining a lame dog through palpation. The student's prior encoding and storage of the dog's musculoskeletal anatomy and the process for examining a lame dog will influence the quality of the anatomical and procedural information the student retrieves and, ultimately, the quality of their examination and conclusions.

The process of memory retrieval, like memory encoding, often depends on the strategy used. Strategies designed to enhance the retrieval of long-term memory may involve simple or complex approaches. For example, a simple approach to fostering retrieval is the use of **retrieval cues**. Retrieval cues are clues or aspects of the environment that become associated with information when it is learned (or in subsequent learning). These cues can be internal (e.g., emotions, thoughts) or external (e.g., words, images, odors) and influence the ability of an individual to retrieve the encoding information. Cues operate by activating long-term memories that can then be transferred into working memory for use. The smell of an anatomy lab may lead to a flood of memories when lab specimens are placed on display for a final exam, or a funny acronym that an instructor makes up to help students remember the number of taeniae in each section of the equine intestinal tract becomes a mnemonic that stays with the students for years. The more specific and distinctive the cue, the better trigger it may be for activating the encoded memory. This use of retrieval cues is a form of *encoding specificity*, that is, when the context at encoding (learning) is similar to the context at retrieval (performance), retrieval is enhanced (Godden and Baddeley 1975; Tulving and Thomson 1973). Encoding specificity may be broken down into two components: *content-dependent memory* that focuses on the external context present during learning (e.g., location, sounds) and *state-dependent memory* that focuses on the internal context present during learning (e.g., anxiety, mood, fatigue). For example, taking the anatomy exam in the same lab where anatomy class was taught can increase the likelihood of the smells triggering specific details needed for the test.

In relation to Atkinson and Shiffrin's model, memory encoding, storage, and retrieval form a complex interrelationship of storage and processing that influence an individual's ability to think and act. The interaction between sensory memory, working memory, and long-term memory creates an adaptive system of attentional control, meaning making, and flexible performance. The discussed learning and memory strategies – chunking and retrieval cues – are just the tip of the learning, memory, and cognition iceberg (see the Fostering Deep and Flexible Long-Term Knowledge section below).

Part 2: Conceptual Knowledge

A central aspect of learning, memory, and cognition involves determining patterns in prior knowledge and experience and representing these patterns in a meaningful organization. These organizational representations allow for the integration and synthesis of various aspects of knowledge, including episodic and semantic knowledge, and to a lesser extent procedural knowledge. In addition, these organizational representations – categories, networks, schemas, and concepts – provide benefits beyond simple organization to include: (1) the ability to make inferences and predictions, (ii) the ability to communicate, (iii) the ability to reduce cognitive load, and (iv) the ability to facilitate or inhibit the learning of new knowledge (Carey 2009; Rosch et al. 1976).

1) Conceptual knowledge allows an individual to *infer* from prior knowledge and experience in order to better understand new knowledge and experience. This better understanding may also lead to the ability to *predict* unseen properties of an object or the likelihood of future events.

   For example, a veterinarian who is examining a lame horse may infer from the horse's gait abnormalities that the lameness is associated with the musculoskeletal system or perhaps the nervous system. This inferencing will then guide the veterinarian as they talk to the client, examine and evaluate the horse, and work to narrow the diagnosis. Once the veterinarian determines the cause of the lameness, they can predict the likely needs and courses of action for the client and horse.
2) Conceptual knowledge facilitates *communication* through the use of terms, concepts, and labels that summarize a corpus of knowledge, rather than having to rely on explaining each idea. Domain-based jargon (e.g., ADR means Ain't Doin' Right; HBC means Hit By Car, Fx means Fracture) is often considered in a negative light, but for those that understand the domain knowledge, jargon can lead to significantly easier communication.

   For example, if a veterinarian were to say to a student, "This cat has Grade II periodontal disease and resorptive lesions. Please conduct an oral exam and interpret these dental radiographs," the veterinarian is communicating information about the cat's condition (Grade 2 periodontal disease and resorptive lesions) and the need for assessment (oral exam and interpretation of dental radiographs) without having to explain the knowledge behind the condition and the diagnostics.
3) Conceptual knowledge reduces *cognitive load* by condensing information into packets of knowledge. In addition, since these packets (i.e., schemas and concepts) include regularities of useful knowledge, they help an individual to focus on information that has been demonstrated to be beneficial, rather than a representation of everything one knows or has experienced.

   For example, a veterinary student examining a cat for digestive distress does not need to maintain all of their knowledge regarding the digestive system in working memory all at once; rather, they can begin with relevant questions of the client regarding their cat. These questions may allow the student to narrow the field of interest (e.g., gastroenteritis, colitis, pancreatitis, hair ball) at which point they can focus their knowledge on one or two potential causes in particular, which may represent the symptoms, tests, and treatments for those disorders.

4) Conceptual knowledge can also facilitate or inhibit *learning* and *memory*. To start, conceptual knowledge provides an organized foundation of prior knowledge. However, this foundation of knowledge can both facilitate the learning of new knowledge that can be integrated with the existing conceptual knowledge or inhibit the learning of new knowledge that contradicts existing conceptual knowledge (Alba and Hasher 1983). In both cases, conceptual knowledge influences how an individual interprets and remembers events. This interpretation can negatively influence learning and memory when prior knowledge (for example, in the form of stereotypes toward clients, animals, or approaches) leads to inappropriate and unproductive inferences, predictions, and behaviors, as well as a lack of openness to learning knowledge that is counter to a held stereotype.

Indeed, a veterinary student who has existing knowledge related to normal animal anatomy and physiology is in a better position to learn knowledge regarding general pathology, as they have existing knowledge regarding animal function. They can use this as a foundation upon which to build their new pathology knowledge. Similarly, it would be challenging to learn about neurological diseases if one does not first have knowledge of neurological anatomy and physiology. In addition, while prior knowledge is generally a benefit to learning, it can also impede learning. A veterinary student who has come to believe that animals do not feel pain the way that humans do, or believes that if an animal is not expressing pain auditorily then they are not actually in pain, may be slow to learn new pain management techniques or new knowledge regarding pain management.

The following examples of conceptual knowledge – categorizations, networks, schemas, and concepts – are not discrete or independent of each other. Each type of conceptual knowledge overlaps and may be broadly thought of as hierarchical, and as such, each of these knowledge forms contributes to the four benefits of conceptual knowledge previously mentioned.

A. Categorization

Categorization is the most general term related to the types of conceptual knowledge and can be understood to include networks, schema, and concepts. A categorization provides a grouping of related information (a category, such as cats, dogs, teaching strategies, and learning processes) that also distinguishes this grouping from other groupings. These groupings may involve episodic, semantic, or procedural knowledge. *Concrete categorizations* are well-defined groupings, often defined by observative features, such as birds and squirrels or knowledge of the respiratory or digestive systems. *Abstract categorizations* are less well-defined, often lacking surface feature similarities, such as ethics, happiness, and care. Individuals may begin their conceptual understanding through concrete categorizations and later develop a more abstract understanding (Quinn and Tanaka 2007).

B. Networks

A semantic network of knowledge tends to represent knowledge hierarchically, with superordinate and subordinate categorizations (Collins and Quillian 1969; see Figure 3.7). The most general properties of a category are

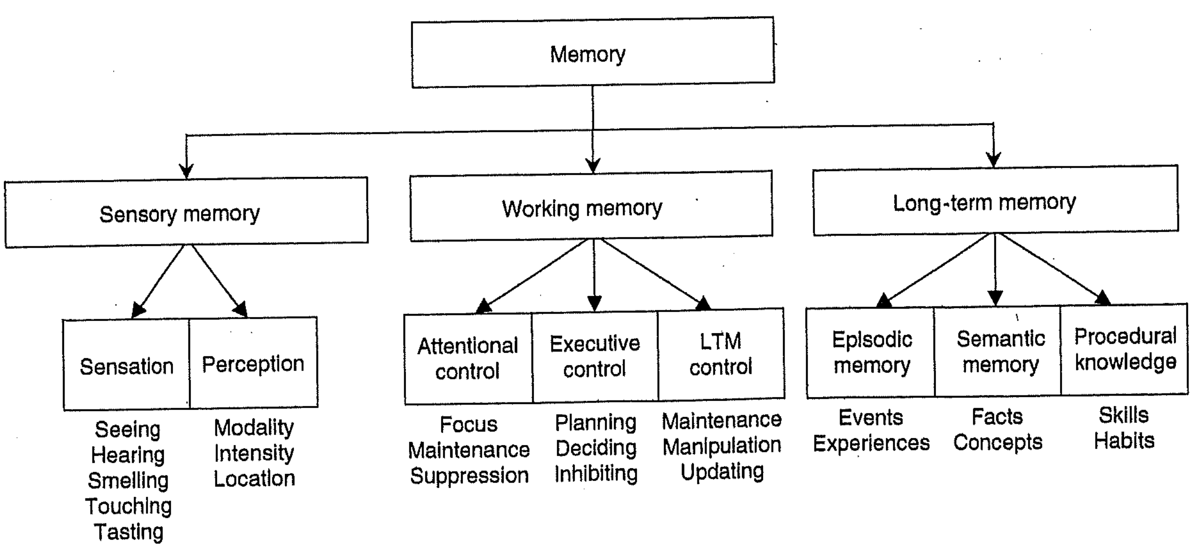


Figure 3.7 An example of a semantic network involving nodes (e.g., sensory memory, sensation, perception) with features (e.g., modality, intensity, location) and organized hierarchically by links (memory" sensory memory" perception).

higher in the structure, while more specific properties are represented lower in the structure. Within the structure exists nodes (attributes), features (elements), and links (relations). Higher nodes generalize to lower nodes such that sensory memory, working memory, and long-term memory are all properties or examples of memory. Nodes closer together tend to be more highly related than nodes farther apart; thus spread of activation will tend to impact nodes that are closer to the originally activated node and dissipate as the spread moves from node to node.

C. Schemas

While a network of categories and their relationships provides organizational information, it does not provide information regarding our general understanding of the categories or specific instances within it. A **schema** is an organizing framework that relies on the abstraction of regularities from a series of specific concept and event experiences (event-based schemas are sometimes referred to as scripts). For example, a veterinary student may be able to read about how to conduct a client consultation, but it is in the repeated experiences of conducting these consultations that the student is able to develop a schema that guides their future consultations. These developed consultation schemas contain the common attributes and behaviors that lead to a successful consultation. Attributes and behaviors that are not common or that do not contribute to a successful outcome do not tend to be included in the schema. Thus, schemas reduce or condense the potentially vast amount of information available in experiences into a more manageable and useful generalization (Bartlett 1932; McVee et al. 2005; Ost et al. 2022).

Once a schema is formed, however, it is not stagnant; instead, it evolves as new relevant experiences are accumulated. New experiences that validate the existing schema will lead to a strengthening of the schema and new experiences that challenge the existing schema or are deemed common and important, but not yet included in the schema, will lead to revisions in the schema. Schemas, developed from prior experience, have a significant impact on current learning, understanding, and experience. Consider a veterinarian entering a new exam room for the first time. They will enter the room with an exam room schema in mind, one that represents a generalization of exam rooms within which they have conducted exams previously. This exam room schema may contain information such as typical room size, lighting options, exam table, small animal scale, seats for clients, sink with running water, artwork, materials cabinets, small equipment, refrigerator, computer, sharps container, and trash can (see Figure 3.8). A veterinarian's schema-based expectations will influence their thoughts and behaviors (e.g., "I don't need to bring exam gloves into the room with me, there will be some in the cabinet"). However, not all elements are equally represented in a schema. Of the elements in the exam room schema, some are more likely to be present (e.g., exam table, seats, materials, and equipment) than others (e.g., lighting options, refrigerator, computer). Finally, schemas may contain other schemas. That is, of the elements listed in a generalized exam room, a veterinarian may have a schema for materials cabinets, a generalized representation of what is likely to be in the materials cabinets, such as gauze, alcohol swabs, scissors, gloves), or the exam room schema may be included itself in a larger schema of a veterinary clinic layout (see Figure 3.8).

An event-based schema, or **script**, condenses the steps typically present in an event or action by focusing on the steps that are typical in the successful completion of the event or action (Bower et al. 1979). These scripts impact an individual's understanding of events or actions, allow for

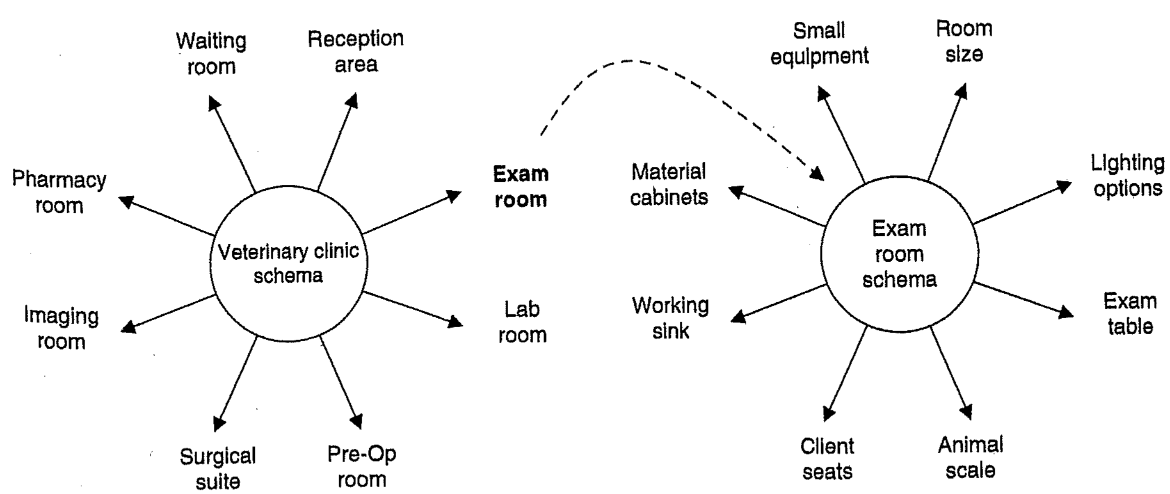


Figure 3.8 Schemas represent a generalization of knowledge and experience, such as typical elements in a veterinary clinic layout. In addition, schemas may contain other schemas, thus the exam room schema is an element of a larger veterinary clinic layout schema.

inference and prediction relative to the events or actions, and influence how they later remember the event or action. A veterinarian, over time, may develop a script for conducting an exam on a cat in respiratory distress that includes several steps: obtain a medical history, perform a physical exam, consider differential diagnoses, develop a diagnostic plan, run and interpret diagnostics, and initiate a treatment plan. It should be noted that not all veterinarians will develop the same script for a respiratory case, although there is likely to be substantial overlap. Finally, while a domain-specific script may be developed and explicitly taught to veterinary students, this official script is likely to be augmented by the individual's personal experiences.

D. Concepts

While categories represent broad labels, networks represent hierarchical organizations, and schemas represent typical elements extracted from experiences, concepts are detailed or concrete representations of objects and events in the world around us that tend to be more defined than schemas (Carey 2009; Nesbit and Adesope 2006). As mentioned previously, categories, networks, schemas, and concepts overlap extensively, so if schemas and concepts seem similar, they are.

Concepts (such as animal, horse, health care, and differential diagnosis) are typically learned through *positive instances* and *negative instances*. A young child with a dog may label a horse and a cow as "dog," since they all have four legs, fur, a face, and a tail. These features are the same as the dog that lives with the child and is perceived as similar, especially from a distance. Ultimately, however, the child will begin to differentiate these animals based on particular defining *features*, such as body size, shape of the face, and movement. This differentiation into separate concepts is facilitated socially when others label a horse a "horse," a cow a "cow," and a dog a "dog." This differentiation is provided by positive and negative examples of each. This differentiation will continue as the child is introduced to sheep, pigs, and llamas, and the veterinary student is introduced to the Clydesdale, the American Quarter Horse, and the Shetland Pony, or the Great Dane, the Golden Retriever, and the Chihuahua.

Beyond features, which can sometimes be difficult to delineate, individuals can represent concepts through the use of exemplars and prototypes. Representing a concept via *exemplars* involves remembering several examples of the concept. For example, remembering "cow" based on remembrances of a Holstein cow, a Hereford cow, and a Black Angus cow at a county fair. Exemplars provide both a sense of the essential features of the concept and the recognition that there is variability in the concept. In addition, there is evidence that we can also represent a concept through a *prototype*, or one typical example of the concept. For example, a veterinary student may have a prototype in mind for a heart that involves a diagrammatic image of a heart with four neatly drawn chambers, well-labeled valves, and red and blue arteries and veins. Another prototype might be an image of a Rambouillet sheep for "sheep" or a Quarter Horse for "horse."

1) *Developing Concepts*. Individuals can come to develop concepts from the top down, through a teacher-centered process where veterinary students (i) are provided with positive and negative instances of a concept, (ii) extract defining features of the new concept, and (iii) develop a concept definition (concept attainment). Students may also learn concepts from the bottom up, through a student-centered process of (i) generalizing from everyday or known experiences to generate the concept, features, and definition, followed by (ii) using the developed concept to predict, explain, and verify new instances or observations (concept formation). Both concept attainment and concept formation focus on students developing well-defined understandings of concepts, and empirical support exists for both approaches.

   Whether using concept attainment or concept formation, concepts are better understood when (i) the defining features are salient and distinct; (ii) the provided definitions are clear and include the defining features, especially when the defining features are subtle or vague; (iii) the concept is explained within the students' prior knowledge of other concepts; (iv) the first examples are simple and clear positive instances, with subsequent instances less clear and more challenging; (v) positive and negative instances are provided simultaneously; and, (vi) both definitions and examples are presented (or developed) during the learning process (Aslin and Newport 2012; Kornell and Bjork 2008).
2) *Conceptual Change*. While developing new concepts can be a challenge, fostering conceptual change is significantly harder. Conceptual change involves more than a slight refinement in one's understanding; it entails a significant transformation in one's representation and application of a concept (Chi and Roscoe 2002; DiSessa and Sherin 1998; Duit and Treagust 2003). Examples of extensive concept change would include a shift from understanding science as a search for facts to the development of an integrative process for expanding understanding of the world around us based on evidence. In veterinary medicine, conceptual change may include a shift from thinking of veterinary medicine as the act of vaccinating puppies and kittens to an understanding of the veterinarian's role in promoting a "One Health" approach, in which veterinarians are integral in ensuring animal health while considering its interdependent relationships with human, public, and environmental health. On a less expansive scale, conceptual

change can also involve the development of knowledge from basic facts and figures to a more sophisticated and nuanced understanding and application.

Fostering conceptual change is a challenge and may vary depending on the concepts to change. The process can be intensive and requires significant engagement on the part of the student and instructor (Dole and Sinatra 1998; Posner et al. 1982; Schnotz and Bannert 2003; Vosniadou 1994; Zuccarini and Malgieri 2022). To engage students in conceptual change, one should attempt to:

- *Foster the identification of preconceptions and engage in the detection of discrepancies.* It is important for students to understand their own knowledge and how they see the world. What do they know, believe, and value? In addition, how do students' understandings, beliefs, and values align with those espoused by the field of veterinary medicine? In general, identifying preconceptions and detecting discrepancies in students' understandings, beliefs, and values are facilitated by (i) student active engagement (e.g., lab and live animal experiences, discussions, problem-solving), (ii) student explicit reflections on new versus prior knowledge (e.g., journaling, discussions, reflection prompts), (iii) student engagement with multiple representations (e.g., data-based graphs and diagram, discussions, readings), (iv) student interactions with peers (e.g., peer feedback, group discussions, group projects), and (v) instructor feedback emphasizing discrepancies (e.g., post-lab notes, discussions, comments based on reflection prompts).
- *Engage students in cognitive conflict supported by explanations and feedback.* One purpose of the identification of preconceptions and the detection of discrepancies is the generation of cognitive conflict, a state of uncertainty and, potentially, discomfort resulting from the realization of discord between one's knowledge, beliefs, and values and those of new information or experiences. This new information needs to be supported by clear explanations of the discrepancies and feedback on the students' understanding of these discrepancies. The rationale for the cognitive conflict is to motivate a student to engage in a reevaluation of their understanding, beliefs, or values in light of the realized discord. Are changes desired and how might these changes be fostered?
- *Foster the accommodation of new knowledge and experiences.* As students become motivated to initiate change, the challenge becomes modifying, or accommodating, one's knowledge representations and personal beliefs and values based on the new knowledge and experiences. Accommodation involves modifying existing or creating new understandings, beliefs, or values that better align with the new experiences. The development of these new representations involves repeated experiences in testing and validating one's understanding through active engagement.
- *Promote active engagement, including practice with feedback and generalization.* In addition to identifying uncertainties and discrepancies, as well as adapting one's knowledge, beliefs, and values based on new information, students should be provided with opportunities to apply and test their new understandings in existing and new contexts or situations through active engagement in problem-solving, peer discussions, client and animal interactions, and lab experiences. It is through these new applications that students can develop new generalized categories, networks, schemas, and concepts.
- *Foster student reflection for the purpose of accommodation and integration.* Conceptual change is an ongoing process of evaluating one's understanding, as well as new information and experiences, in order to identify and address uncertainty and discrepancies. This process, while often initiated by instructors, ultimately should be self-regulated by the student. This self-regulation process can be fostered by encouraging student reflections to identify uncertainty and discrepancies, adjust existing understandings or reframe new knowledge and experience, and integrate or synthesize new and prior knowledge and experiences.

Ultimately, initially expending the effort to learn new concepts accurately, is much easier than trying to change concepts afterward. That said, conceptual change is an important process for students to possess, as a career in veterinary medicine will require continuous adjustments to one's explicit and implicit knowledge.

Part 3: Fostering Deep and Flexible Knowledge

Learning is a function of processing: what we process we learn. This processing, within the idiosyncrasies of human memory, has the potential to result in deep and flexible knowledge, specifically knowledge that is accessible with little or no effort, knowledge that is interconnected with other relevant knowledge, and knowledge that is applicable across a variety of purposes and contexts. Deep and flexible knowledge can be seen when a veterinarian evaluates a horse by asking questions of the client, observing the horse, activating relevant knowledge based on what they have seen and heard, integrating and inferring from what they have seen, heard, and activated, all in order to form a differential diagnosis list. Ultimately, gaining knowledge and experience across a career will lead the veterinarian toward expertise, resulting in faster, more accurate, less effortful, and more applicable knowledge and skills.

As discussed at the beginning of the chapter, learning and performance are intricately linked such that deeper processing during learning generally results in increased levels of performance (depth of processing). Similarly, aligning the type of processing (transfer appropriate processing) or aligning the context of processing (encoding specificity) between the learning and performance situations also generally results in increased levels of performance. This learning–performance relationship can be extended when examining one's intent to learn. Specifically, does it matter if one intends to learn? Yes. No. It depends.

In the 1960s and 1970s, a focus of research evolved to examine whether the **intent to learn** impacted learning (Hyde and Jenkins 1969, 1973; Walsh and Jenkins 1973; see also Craik 2023; Oberauer and Greve 2022). The rationale was based on *depth of processing* (Craik and Tulving 1975), that is, if an individual processed information deeply, they tended to learn more. This led to a related question: Would intent to learn matter if the individual processed information deeply? The short answer is *no*. When individuals process information deeply (meaningfully), it does not matter if the individual intends to learn or not – what we process we learn, whether the processing was intentional or not. Indeed, the intent to learn only matters to the degree that it serves to motivate an individual to engage in deeper processing: "The importance of intentionality lies in its abstract motivational push to perform further processing operations on the event in question" (Craik 2023, p. 302).

This point is significant: Students may learn based on the processing induced through instruction or by the processing initiated by the students themselves. Two revelations: First, *instruction impacts student learning to the degree that the instruction fosters processing*. In the active learning literature (Deslauriers et al. 2019; Freeman et al. 2014; Lombardi et al. 2021), strict lecture instruction (i.e., exposition + note-taking only) is posited as an ineffective method for fostering learning, while student-engaging instruction (e.g., problem-based learning, flipped classroom, small group work) is posited as an effective method. But, why? Why do some instructional strategies foster more learning than others? The answer is processing. The focus on processing helps to address why some strategies, such as flipping the classroom, can be both highly effective and completely ineffective in fostering student learning (see Kapur et al. 2022; Oudbier et al. 2022). Strategies are only effective when their application in the classroom fosters relevant student processing; thus, the effectiveness of instruction has less to do with the strategy itself and more to do with the implementation.

Second, *students' actions impact learning to the degree that these actions foster processing*. For example, students who pay attention during a class and take "good" notes (i.e., making meaning from what the instructor is saying before writing down notes, relating the new notes to prior notes, and highlighting concepts that are still confusing) tend to learn more than students who simply transcribe what the instructor is saying. Students who think about class knowledge outside of class, informally, tend to learn more than students who only think about class prior to an exam. And, students who study across several sessions, talk aloud to themselves during studying, and generate their own summaries will learn more than students who simply reread their notes. Unfortunately, students often engage in learning strategies that have been demonstrated to be ineffective, such as rehearsal or cramming, while eschewing learning strategies that have been demonstrated to be effective, such as summarizing and self-testing (Blasiman et al. 2017; Hartwig and Dunlosky 2012; Morehead et al. 2016).

Thus, while both *intentional* and *incidental processing* may lead to learning, depending on the relevance of the processing to the task to be performed, both are not required. Indeed, previous research has demonstrated that when incidental learning is sufficient for learning a task, additional intentional learning is not beneficial (Evans and Baddeley 2018; Hyde and Jenkins 1969; Oberauer and Greve 2022; Postman and Adams 1956). Just to be clear, the first point here is *not* that intent to learn is unimportant or ineffective, but rather, that **processing is the proximal cause of learning** and that the intent to learn is effective to the degree that it motivates students to engage in effective (meaningful) processing. In addition, the second point is that *teaching matters* and that teaching matters to the degree that it fosters processing that is relevant to the instructor's outcomes for the course.

What follows is a discussion of actions and effects that foster processing and, thus, impact learning. As noted, while these actions and effects foster processing, their effectiveness depends on their implementation. Finally, these actions and effects are not independent and cannot be parsed into individual and discrete boxes – there is significant overlap because learning is neither neat nor tidy. For example, the generation effect, which posits that self-generating meaning leads to greater learning than simply watching a presentation, overlaps with the retrieval practice effect, which posits that retrieving information from long-term memory (which is required to make meaning) also leads to greater learning than simply watching a presentation, which overlaps with the spacing effect, which posits that generating and retrieving information leads to greater learning when they are distributed over time rather than massed in a single session. If you find yourself saying, "This sounds a lot like . . . " or "This seems to be related to . . .," that is a good thing – you are processing. Finally, everything about to be discussed comes under the depth-of-processing umbrella and the heuristic of, *what we process we learn*.

A. Learning, Forgetting, and Practice

The relationship between learning and performance follows the fairly standard form of a power function (see Figure 3.9a), with more learning early in practice and less learning overtime (Crossman 1959; Snoddy 1926). This ***Power Law of Learning*** relationship is evident across various tasks from language learning (Graves and Garton 2017), to musical instrument proficiency (Lehmann and Ericsson 1997), to memorization (Cepeda et al. 2009). More recently, Heathcote et al. (2000), indicated that while a power function fits the aggregated data across participants, on an individual basis learning follows more of an exponential function. Interestingly, forgetting tends to follow a similarly shaped power function (see Figure 3.9b), decreasing more immediately after the cessation of learning and tapering off less over time forming the ***Power Law of Forgetting***. This relationship is also evident across various functions, such as language learning (Bahrick 1984), skill learning (Walker et al. 2003), and memorization (Wickelgren 1975).

As a general course, when one stops learning, one starts **forgetting**. Unfortunately, the exact details regarding why one forgets are both multifaceted and imprecise (Schacter 2002). In some cases, memories are not forgotten; they were never encoded in the first place. This lack of initial learning may be due to a lack of attention or processing during encoding, or in some cases, due to the presence of memory-impeding pharmaceuticals in the blood, such as alcohol, benzodiazepines, and opioids. If memories are appropriately formed, memory failure may be the result of general decay, poor retrieval, or information interference. First, in the case of ***decay***, the strength of memories may decrease due to a lack of use to the point where the memory become inaccessible (Hardt et al. 2013; Ricker et al. 2016). This does not mean that the memory is completely gone, but only that the memory cannot be activated back to a conscious level. In such cases, relearning the knowledge or skill typically takes less time than the original learning, indicating that the individual was not starting from scratch. Second, forgetting may be due to ***retrieval failure***, where a memory is inaccessible due to the lack of an appropriate cue to activate the memory (Shiffrin 1970). It is common to have a feeling that one knows something (e.g., the name of a piece of equipment or someone's name), but simply cannot seem to retrieve it. In this case, searching for an appropriate cue (e.g., when is the equipment used, or an image of the person's face) may retrieve the memory more effectively than attempting to retrieve the memory directly. Finally, forgetting may be the result of ***interference***, when one memory makes it difficult to retrieve another memory (Barrouillet and Camos 2009; Lewandowsky et al. 2008). For instance, if a person who lived in Louisiana with a 504 area code moves to Virginia with a 540 area code, they may have difficulty upon first moving in retrieving their new area code due to the interference of their old area code. Additionally, veterinary students may struggle to remember the proper way to bandage a catheter in the ICU at the vet school due to interference from the method they were taught at their old clinic, or interference could be caused by a surgical video viewed during vet school which prevents them from learning/recalling new and unfamiliar protocols on a surgical clerkship in their final year.

Beyond initial learning and forgetting, as an individual continues to practice and gain experience, they may develop ***expertise***. Specifically, with practice and experience, they add new knowledge and skills, organize existing knowledge and skills into more effective and integrated formats, generalize knowledge and skills into schemas and concepts, and develop fast and efficient domain-specific skills. The development of expertise is a continuum, with knowledge and skills improving over time. While there have been estimates of how much time it takes to become an expert – 5,000 hours, 10,000 hours, 10 years – there is no magic number and the time it takes will depend on the nature of the practice, the nature of the task, and the nature of the individual. What is known is that expertise takes a lot of practice over a long period of time.

In addition, there are a number of theories associated with the development of expertise, especially skill-based

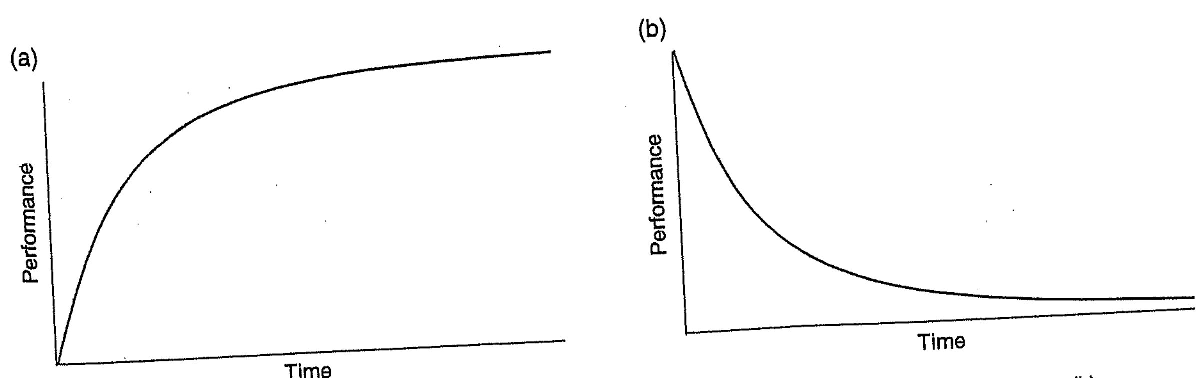


Figure 3.9 A generalized representation of the Power Law of Learning (a) and the Power Law of Forgetting (b).

expertise, and several of them propose three overlapping stages of expertise development (Anderson 1982; Fitts 1964; Kim et al. 2013). The stage names proposed by Anderson (1982) – *declarative, transitional*, and *procedural* – align the development of expertise with the acquisition and refinement of declarative and procedural memory. In this case, the **declarative stage** of expertise involves the acquisition of primarily declarative memory (e.g., facts, concepts, terminology, structures), including processes that are stored in memory as a step-by-step list (this list would be conscious and something the student would write down or talk about). It is common for a novice at the declarative stage to rehearse or talk themselves through the steps of a skill. The declarative stage is typified by slow and error-prone performance that requires high levels of attention and effort. Specifically, for a novice, a new skill generates high cognitive load, as what to focus on is uncertain, decision-making is unreliable, knowledge is poorly organized, and skills are imprecise in execution – all of this effort comes at a high working memory cost that often leads to mistakes.

As an example, a veterinary student learning to spay a cat will need to know the essential reproductive anatomy and physiology of a cat, the basics of instrument and suture handling, soft tissue handling and hemostasis, and the elements involved in preoperative preparation, surgery, and post-op care. A student new to spaying a cat will perform these tasks slowly and intentionally, as they become acquainted with using the instruments and suture on a live animal, learn how much tension they can place on tissue to gain visualization, and work to determine how to properly engage the external rectus fascia and the intradermal layer when closing.

As an individual continues to practice and gain experience, they will enter the **transitional stage,** where they begin to develop more refined declarative memory, in the form of conceptual knowledge (i.e., schemas and concepts) that will entail a better understanding of the context and conditions within which the skill resides. The bulk of the transitional stage, however, will involve *proceduralization*, which involves the refinement of several individual, declaratively driven steps into a single procedural step where the actions become more automated and more accurate. Proceduralization through practice allows the individual to engage in elements of the skill without having to think about them, thus reducing cognitive load.

As the surgical student is given the opportunity to perform multiple cat spays, they gain efficiency and proficiency in this stage, as each individual step in the declarative stage begins to move toward proceduralization. For example, making the initial skin incision, undermining the subcutaneous tissue, identifying the linea alba, making an initial stab incision into the abdomen, and extending the abdominal incision all become "the opening" and are performed more efficiently. However, such skills do not become automated overnight, and skills often become part automated and part conscious.

Finally, the **procedural stage** involves the continued refinement of the skill such that more of the skill becomes proceduralized. As the skill becomes more proceduralized, and with the individual accessing declarative memory less often, the declarative memory upon which the skill was initially built often fades. For example, when one learns to type well, one often forgets where the letters are on the keys. The person can type quickly, but to answer the question, "Where's the W key?," they will need to first type that key in their mind. Ultimately, after practice and proceduralization, the individual will be able to engage in a skill quickly and accurately, and with little cognitive load. For example, the high quality, high volume spay/neuter veterinarian will perform a cat spay in under five minutes and often does not remember the details of the last procedure. Keep in mind, however, that the cost of proceduralization is conscious access to the declarative memory and component skills that led to the expertise. It is this forgetting of the relevant declarative knowledge and component skills that often result in experts becoming poor teachers. Thus, a highly trained veterinarian who begins to teach may need to relearn sets of declarative knowledge or component skills to be better able to explain and model the entire process.

B. Rote, Meaningful, and Elaborative Learning

In the pursuit of learning, meaning is paramount. As previously discussed, engaging new information in a deep and meaningful way (depth of processing) leads to increased retention. This concept that meaningfulness increases learning is present in the concepts of rote, meaningful, and elaborative learning. ***Rote learning*** involves learning through memorization in the absence of significant meaning making or knowledge structure creation such as schemas or concepts (Cho and Powers 2019; Grove and Bretz 2012). This type of learning tends to foster weak memories that are poorly organized and poorly connected to prior knowledge, resulting in more forgetting, less inferencing, and less usefulness in solving new problems (Karpicke and Grimaldi 2012). Consider a veterinary student who is learning anatomy by way of flash cards. On one side of the flash card is a diagram of the canine lymph nodes and vessels, with the nodes and vessels numbered, and on the other side are the names of the nodes and vessels by number. What the student is learning are dissociated facts (which number on the diagram goes with which name) and a simple diagram, not a greater understanding of the function of lymph nodes, how to locate lymph nodes on a live animal, or the diagnosis and treatment of diseases such as lymphoma. Ultimately, if the student is asked a question different from "What are the lymph nodes of the hind limb?," they are likely to be at a loss.

In contrast to rote learning, ***meaningful learning*** focuses on the generation of understanding through the association of new knowledge and experience with prior knowledge and experience, emphasizing knowledge comprehension, application, and integration (Ausubel 1960; Dochy et al. 2003; Furtak et al. 2012). In creating meaningful associations, the new knowledge is integrated into the existing conceptual knowledge organization, forming relationships that immediately benefit the understanding of the new knowledge. Meaningful learning tends to foster deep and flexible memories that are highly organized and structured, resulting in greater meaning, inferencing, and usefulness. Considering the veterinary student learning the lymphatic system, their understanding would benefit from strategies such as elaborative learning, which emphasizes connections between new and prior knowledge.

Elaborative learning, or sometimes termed *elaboration*, is a generalized approach for developing deep and flexible knowledge that is focused on proactively connecting new and prior knowledge to generate meaningful connections and meaningful learning (Anderson and Biddle 1975; Dunlosky et al. 2013). Specifically, elaborative learning is focused on actively connecting new knowledge with prior knowledge to emphasize the addition of new connections (see Table 3.1). Elaborative learning, however, is not a single strategy, but rather, a generalized approach to fostering meaningful learning that may involve a multitude of strategies, such as summarizing, concept maps, self-explanation, analogical reasoning, and elaborative interrogation (Brod 2021; Chi et al. 1989; Gentner et al. 2003; Pressley et al. 1995).

For example, *elaborative interrogation* involves a student being asked to "interrogate" an idea or concept by providing an explanation or application, often by answering *why* or *how* questions (Froehlich and Rogers 2022), although the nature of the questions may vary. For example, in a presentation addressing kidney function, an instructor may ask, "How does proper kidney function contribute to overall animal health?" In answering this question, the student will need to connect the new knowledge regarding kidney function with their prior knowledge regarding animal health, resulting in meaningful learning (rather than rote learning). In addition, in a unit on feline health, students may be asked, "Why is cat dehydration problematic?" for students to clarify, within themselves, the relationship between hydration, dehydration, and systems functioning. The key in elaborative interrogation is that the questions foster explanation (deeper learning) and connection (flexible learning), not the simple retrieval of answers already provided in class or lab.

Another elaborative learning strategy related to elaborative interrogation is *self-explanation*, where the learner self-generates their own definitions, explanations, inferences, or evaluations. Thus, self-explanations help to connect new knowledge to prior knowledge, making the knowledge more personally meaningful, and to evaluate the completeness of one's comprehension, monitoring one's understanding, and working to rectify gaps. Self-explanations may include delineating the steps in a procedure, explaining the

Table 3.1 Definitions and effect sizes for empirically supported learning effects.

Learning effect	Definition	Effect size
Elaboration effect	Learners tend to remember information better when they engage in deeper, more meaningful processing of new information, and actively make connections between new and prior knowledge.	Medium[a] ($g = .55$)
Retrieval effect	Learners tend to remember information better when they actively recall the information from memory, rather than simply rereading or restudying the information.	Medium[b] ($g = .61$)
Generation effect	Learners tend to remember information better when they actively generate it themselves, rather than passively receiving it through reading or a presentation.	Medium[c] ($d = .40$)
Spacing effect	Learners tend to remember information better when they engage in study sessions or practice trials that are spaced out, or distributed, over time, rather than massed into a single session.	Large[d] ($g = .74$)
Interleaving effect	Learners tend to remember closely related information better when they alternate between topics under study, especially when they have similarities that might be confusing, rather than focusing on one topic at a time.	Medium[e] ($g = .42$)
Enactment effect	Learners tend to remember information better when they engage in physical actions related to the information, rather than simply observing or reading about the action.	Large[f] ($g = 1.23$)
Production effect	Learners tend to remember information better when they read words aloud (or type, write, or spell words or phrases), rather than reading words silently.	Medium[g] ($g = .50$)

[a] Citations: Bisra et al. (2018).
[b] Adesope et al. (2017).
[c] Bertsch et al. (2007).
[d] Latimier et al. (2021).
[e] Brunmair and Richter (2019).
[f] Roberts et al. (2022).
[g] Fawcett (2013).

structure and function of a system, predicting the impact of specific remedies, or clarifying the relationship between observed symptoms and hypothesized causes (Fonseca and Chi 2011). In addition, self-explanation may be individually driven, where a student spontaneously engages in self-questioning or comprehension monitoring or instructor driven, where self-explanations may occur as a result of prompting by the instructor.

Meaningful and elaborative learning both emphasize the importance that meaning and connection make in fostering long-term memories. Specifically, learning is based on meaning, and meaning is created through associating new knowledge and experience with prior knowledge and experience. For example, a veterinary student may take classes on the "normal animal" to begin the process of building knowledge related to the general structure and function of animals, in general, followed by more specific courses designed to integrate a deeper understanding of various animal systems (e.g., circulatory system, musculoskeletal system). However, students need to be encouraged to make connections within and across these courses through the use of elaborative learning strategies, such as elaborative interrogation and self-explanations, so that their knowledge develops into complex conceptual knowledge and well-practiced procedural knowledge.

C. Retrieval Practice Effect and Generation Effect

The ***retrieval practice effect***, sometimes termed (unfortunately) the *testing effect*, indicates that actively retrieving or recalling information from memory, as opposed to simply reexperiencing the information through rereading or a presentation, leads to increased long-term retention, transfer of knowledge, and deeper understanding (Agarwal 2018; Roediger and Karpicke 2006; Zaromb and Roediger 2010). In addition, the retrieval practice effect has been demonstrated to be incredibly robust in its application, resulting in learning increases across subject areas (e.g., STEM, medicine, humanities), student populations (e.g., elementary, secondary, college students), and simple and complex materials (e.g., facts, concepts, relationships, inferences).

A classic study of the retrieval practice effect was conducted by Roediger and Karpike (2006, Experiment 2), who had students read and learn a passage of approximately 260 words containing 30 idea units. Students were assigned to one of three learning groups, such that one group (SSSS) studied the passage for five minutes ("studying" was defined as rereading the passage and students were able to reread the passage approximately 3.5 times during each five-minute study period), followed by a short two-minute break, four times in a row (i.e., study, break, study, break, study, break, study, break). The second group (SSST) studied the passage three times, followed by taking a recall test where they were given a blank sheet of paper and asked to recall as much information from the passage as possible, in 10 minutes, regardless of wording or order (i.e., study, break, study, break, study, break, test, break). Finally, the third group (STTT) studied the passage once, followed by three testing periods (i.e., study, break, test, break, test, break, test, break). Half of the students from each group completed a final recall test 5 minutes after the completion of their treatment (SSSS, SSST, or STTT), while the other half of the students from each group completed a final recall test one week later.

Roediger and Karpicke found that for the five-minute delayed post-test, the SSSS group recalled more than the SSST group who recalled more than the STTT group (see Figure 3.10). However, for the one-week delayed post-test, the students' performance reversed, such that students in the STTT group recalled more than the SSST group who recalled more than the SSSS group. These findings indicate that while rereading the passage over and over (SSSS) led to significant gains in the short term, retrieving information regarding the passage from memory (STTT) led to longer-term gains. In interpreting these results it is clear in Figure 3.10 that a key finding was that the students who engaged in more information retrieval (STTT) forgot less over time than the students who engaged in more information exposure (SSSS).

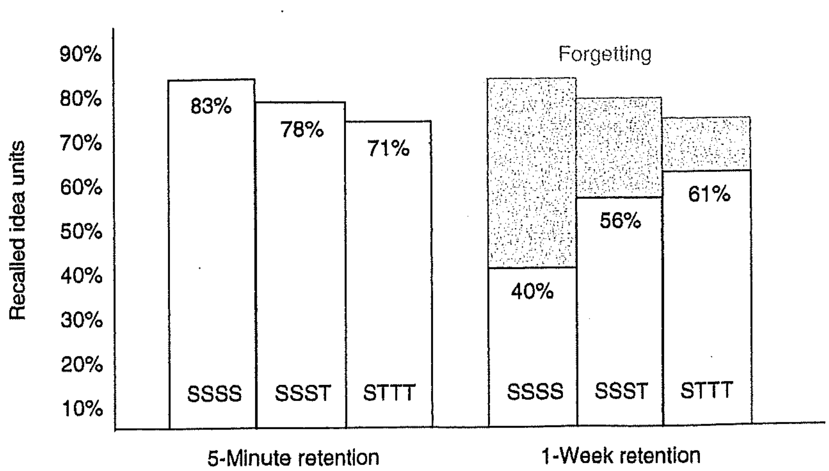


Figure 3.10 Mean recall of idea units on 5-minute delayed and 1-week delayed retention tests for students in each learning condition (SSSS, SSST, STTT). The amount forgotten after one week is represented by the gray bars. *Source:* Original figure, adapted from data reported in Roediger and Karpicke (2006). Copyright 2006 by the Association for Psychological Science.

Considering reviews and meta-analyses of the retrieval practice effect, Adesope et al. (2017; see also Agarwal et al. 2021; Rowland 2014) conducted a meta-analysis of retrieval practice focused on the use of pretesting (i.e., one or more practice tests or quizzes during the learning phase) as a method of retrieving knowledge on students' subsequent test performance. Overall, Adesope et al. found medium to large effect sizes[1] of pretesting during learning on students' subsequent test performance; that is, students who engaged in some form of pretesting retrieval practice outperformed students who did not engage in retrieval practice. Of particular interest, however, are the moderating variables explored by Adesope et al. that help to further explain the robustness of the retrieval practice effect. For example, Adesope et al. found a medium effect when pretesting was compared to rereading or restudying and a large effect when compared to engaging in no activity (no pretesting, no rereading, no restudying). Since rereading is a common study strategy for students (Callender and McDaniel 2009; Karpicke et al. 2009), these findings provide evidence that more active retrieval practice is beneficial to retention and test performance than simply reexperiencing knowledge. Adesope et al. also demonstrated that retrieval practice was robust across instructional settings (classroom and laboratory), educational levels (primary, secondary, and postsecondary), and time interval between the retrieval practice and final test (<1 day delay, 1–6 day delay, >6 days delay) with the effect sizes ranging from medium to large in each case. Finally, Adesope et al. found a transfer-appropriate processing effect; in particular, students' final test performance benefitted most when the pretest and final test were identical in processing (i.e., both addressed the same content in the same format, such as multiple-choice questions or short answer questions).

One challenge in understanding the retrieval practice effect is that the discussion often fixates on "testing." It should be noted that the proximal cause of the retrieval practice effect is the processing involved in retrieving that leads to increases in the strength of the memory, not the "test" itself. As Agarwal et al. (2021) state, "it is the *process* of practicing retrieval (the active attempt) that shapes learning, not tests" (p. 1412; italics in the original). Within the retrieval practice effect literature, quizzes are often used as they are easy to create, control, and quantify. However, retrieval could be fostered through any number of tasks, such as problem-solving, discussions, concept maps, self-explanations, and writing. The key to the retrieval practice effect is the fostering of the retrieval of knowledge, not the form of the retrieval itself.

The ***generation effect*** indicates that actively creating or generating knowledge, as opposed to passively reading or watching a presentation created by others, leads to increased learning (Jacoby 1978; McCurdy et al. 2020a; Slamecka and Graf 1978). The generation effect has been demonstrated to be robust across various tasks, including problem-solving, study techniques, worked examples, arithmetic, sentence completion, word pairs, and anagrams. Finally, there is evidence that the generation is more effective in fostering learning when fewer constraints are applied to what is generated (e.g., multiple potential solutions or formats), rather than when more constraints are applied (e.g., a single correct answer). Thus, learning is enhanced when the learner is provided with greater latitude in what is produced (Fiedler et al. 1992; McCurdy et al. 2020b).

For example, Foos et al. (1994, Experiment 2) examined the generation effect in relation to student-created study materials. Specifically, students read and studied a 2,300-word text addressing the life and times of bees. The Generate group was asked to generate study questions, of any format (e.g., essay, multiple-choice, fill-in-the-blank), addressing the information in the text and to be used while they studied. The students in the Receive group each received a set of study questions created by a student in the Generate group to be used while they studied. All students were given 30 minutes to read and study (the Generate group also created their questions during this time) for the subsequent 30-item test consisting of 15 multiple-choice items and 15 fill-in-the-blank items, which was administered shortly after the study period. In addition, the ideas from the text that were addressed by both the study materials and the test items were labeled as "target" ideas, while test items that were not also present in the study materials were labeled as "non-target" ideas. Thus, target ideas were "targeted" by the study materials.

The results of Foos et al.'s study (see Figure 3.11) indicate the presence of the generation effect. Specifically, students who generated study materials did better (89%) than students who simply received study materials (72%) when assessed by "target" test items. In cases where the content of test items was not present in the study materials (nontargets), students in both the Generate and Receive groups performed the same, 54%. The results that student learning was better for test items where the content was also present in the study material (targets), as compared to when the

1 Meta-analyses synthesize multiple experiments examining specific treatment effects (often a comparison between a control group and a treatment group), using statistical analyses to determine an overall or "absolute" effect, stated in terms of an **effect size.** Meta-analyses typically use the Hedges' g or Cohen's d effect size calculations that express the effect in terms of a standardized mean difference between groups such that a Hedges' $g = 1$ or Cohen's $d = 1$ equates to a group difference of 1 standard deviation. Both Hedges' g and Cohen's d are evaluated as a small effect (0.2), medium effect (0.5), or large effect (0.8). Caution, however, should be taken as the value-laden terms small, medium, and large can be context dependent and vary according to domain.

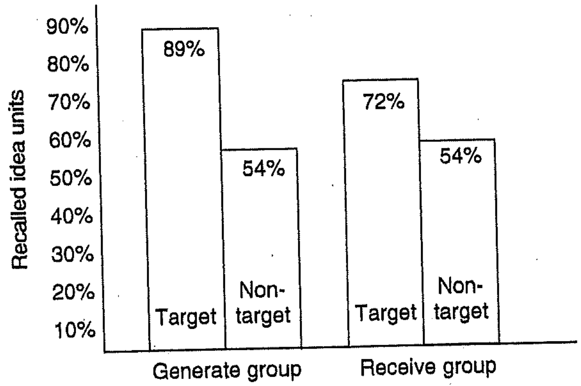


Figure 3.11 Mean test performance for students in both the Generate group and the Receive group for both the targeted ideas (ideas that were present in both the test items and study materials) and the nontargeted ideas (ideas present in the test items that were not present in the study materials). *Source:* Original figure, adapted from data reported in Foos et al. 1994. Copyright 1994 by the American Psychological Association.

test item content was not present in the study material (nontargets), is evidence of transfer-appropriate processing: processing the ideas within the study materials facilitated the processing of the ideas within the test items. Overall, Foos et al. demonstrate that information generated by learners is better remembered than information that is simply read or provided by another.

Considering reviews and meta-analyses of the generation effect, Bertsch et al. (2007; see also MCurdy et al. 2020a) conducted a meta-analysis of the generate effect focused on learning under two broad conditions: read or generate. For example, Peynircioglu and Mungan (1993) used sentence completion, where participants either read the sentence, "Cells of the nervous system are called NEURONS." or generated the end of the sentence, "Cells of the nervous system are called N ______." Pesta et al. (1996) used arithmetic problems, such as "7 x 3 = 21" for the read condition and "7 x 3 = ??" for the generate condition, as well as word pair problems, such as HOT-COLD for the read condition and HOT-C__ for the generate condition. Overall, Bertsch et al. (2007) found a medium effect for the generation effect. Significant moderating variables explored by Bertsch et al. indicated that the generation of responses had a greater effect for meaningful responses (words and numbers) than nonmeaningful responses (nonwords), as well as across all task types (e.g., sentence completion, arithmetic calculations, synonym generation, word completion), except anagrams. Finally, Bertsch et al. found the greatest impact of generation for longer delays in between the generation and the recall test, with immediate and 1-day delays demonstrating a small effect and delays of more than 1-day demonstrating a medium effect.

The retrieval practice effect and the generation effect leverage the fundamental concepts of depth of processing, transfer-appropriate processing, and encoding specificity. Specifically, they emphasize that accessing long-term memories and using them to create new meanings leads to deep (stronger) and flexible (connected) knowledge, resulting in better overall retention, transfer, and application. For example, veterinary students, as they work their way through a course or over four years of lectures, labs, clinics, and clerkships, need to engage continuously in retrieving prior knowledge and skills in order to create new knowledge and skills and solve new problems and challenges. If students are not learning, they are forgetting.

D. Spacing Effect and Interleaving Effect

The *spacing effect* builds on the concept of retrieval practice. The **spacing effect**, sometimes termed *distributed practice*, indicates that learning is enhanced when retrieval practice is distributed over time, rather than focused on a single session, sometimes termed *massed practice* (Cepeda et al. 2009; Cepeda et al. 2008; Wiseheart et al. 2019). The time span for distributing the retrieval practice can be both shorter (minutes to days) and longer (months to years). In addition, the spacing effect has been demonstrated to have a positive effect on the learning of simple and complex information (Gluckman et al. 2014) for younger children and older adults, including motor and verbal skills, and across various learning tasks, such as science and mathematics concepts, musical performance, and video games (Latimier et al. 2021). Of particular import, relative to the spacing effect, is the time between practice sessions (spacing interval) and the time between the last practice session and the performance session (retention interval). First, it appears that all spacing intervals, from short to long, result in better retention than massed practice. Second, it appears that longer spacing intervals facilitate longer retention intervals. And, third, there is some evidence that massed practice may produce better short-term retention, while distributed practice may produce better long-term retention (Cepeda et al. 2009; Donovan and Radosevich 1999; Greving and Richter 2018; Kapler et al. 2015; Roediger and Karpicke 2011).

Considering reviews and meta-analyses of the spacing effect, Latimier et al. (2021; see also Cepeda et al. 2006; Donovan and Radosevich 1999) conducted a meta-analysis of the memory impacts of the spacing effect – spaced retrieval practice versus massed retrieval practice – focused on semantic and verbal stimuli (i.e., not including perceptual or motor learning). Overall, Latimier et al. (2021) found a large effect for the generation effect.

Intimately related to the spacing effect is the interleaving effect. The ***interleaving effect*** indicates that learning new information, especially for closely related information, is enhanced when learning different types of information is integrated, rather than focusing on only one type of information at a time. For example, if a veterinary student is learning basic anatomy across several systems – skeletal (S), muscular (M), cardiovascular (C), and neurological (N) – their retention, transfer, and application will benefit from interweaving questions about each system, S-M-C-N-M-C-S-N-S-M-C-N-C-M-S-N, rather than studying each system in isolation, S-S-S-S M-M-M-M C-C-C-C N-N-N-N, a process called blocking. This concept can be counterintuitive for students, and given a choice, students tend to choose blocking over interleaving (Carvalho et al. 2016; Tauber et al. 2013; Yan and Sana 2021), but this interleaving effect has been demonstrated to be effective across a range of tasks, including mathematical procedures, problem-solving, concept identification, and case studies.

The rationale for the interleaving effect, however, is still being debated. One of the two top theoretical contenders is the *discriminative-contrast hypothesis* that posits that students would learn basic anatomy better through interleaving because experiencing different anatomy categories side-by-side (S-M-C-N) would allow the student to better "see" similarities and differences between the categories (Birnbaum et al. 2013; Kang and Pashler 2012). The second theoretical contender is the *distributed-practice hypothesis* that presupposes that students would learn better because interleaving is really spaced practice, such that S-M-C-N-M-C-S-N-S-M-C-N-C-M-S-N (interleaving) is really **S**-*M*-C-N-*M*-C-**S**-N-**S**-*M*-C-N-C-*M*-**S**-N (spaced practice; Foster et al. 2019). While the rationale for the effectiveness of the interleaving effect is in doubt (Chen et al. 2021; Chen et al. 2022; Sana et al. 2022), the outcome is not.

Considering reviews and meta-analyses of the interleaving effect, Brunmair and Richter (2019) focused on interleaving that involved inductive learning, such as comparing paintings or photographs to determine the names of the painters or the types of birds in the photographs. In addition, their comparisons involved interleaved practice versus massed practice with study materials. Overall, Brunmair and Richter found a medium effect size for interleaving over massed practice. In addition, Brunmair and Richter found a large effect for interleaving involving complex visual materials (e.g., paintings, naturalistic photographs, complex photographs). Finally, Brunmair and Richter found support for the idea that if deductive discrimination between visual materials is the preferred outcome (e.g., learning to interpret blood slides or x-rays), then interleaving works best when materials are presented simultaneously or in close succession, enhancing one's ability to discriminate, rather than spacing the materials out over time.

Rohrer and Taylor (2007) tested both the spacing effect and the interleaving effect. In Experiment 1, addressing the *spacing effect*, students learned how to determine the number of permutations of letter sequences under one of two conditions: massed practice or spaced practice. Students in the *massed practice* group completed four sample problems (with feedback) and four practice problems (without feedback) during the first week, followed by testing a week later that included completing five novel problems. Students in the *spaced* practice group complete two sample problems and two practice problems their first week, two additional sample and practice problems a week later, followed by testing a week later. Thus, students in both groups completed four sample problems and four practice problems. The massed practice group completed them in one session, while the spaced practice group completed them across two sessions. The results of Rohrer and Taylor's Experiment 1 (see Figure 3.12) indicate the presence of the spacing effect. On the test of permutations, the massed practice group answered 49% of the questions correctly, while the spaced practice group answered 74% of the questions correctly.

In Experiment 2, Rohrer and Taylor (2007) tested the *interleaving effect* by having students learn how to find the volume of four obscure geometric solids (circular wedges, spheroids, spherical cones, and half cones) and then practice under two conditions: massed practice and interleaving practice. Students in the *massed practice* group completed two practice sessions, one week apart. Each session comprised viewing a tutorial on determining the volume of one of the shapes, followed by four practice problems addressing that same shape. This tutorial–practice sequence occurred for each of the four shapes (a tutorial followed by four relevant practice problems). Students in the *interleaving* group also completed two practice sessions, one week apart. Each session comprised viewing a tutorial on determining the volume of each of the shapes, one after the other. After these four tutorials were viewed, all 16 of the practice problems were presented and solved in a random order (interleaved). One week later, the students in both groups complete eight novel problems, two of each shape type in a random order. The results of

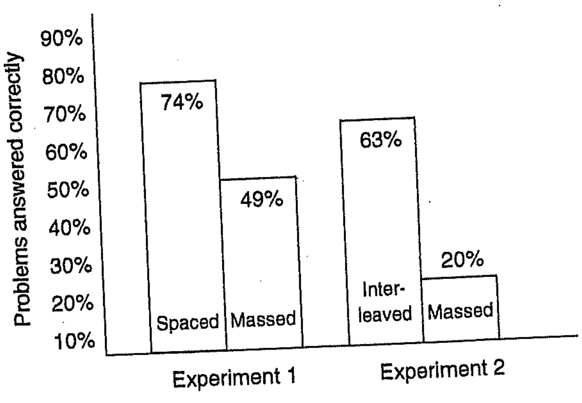


Figure 3.12 Mean correct test performance for students in Experiment 1, spaced versus massed practice of permutation problems, and Experiment 2, interleaved versus massed practice of geometric volume problems. *Source:* Original figure, adapted from data reported in Rohrer and Taylor (2007). Copyright 2007 by Springer Nature.

Rohrer and Taylor's Experiment 2 (see Figure 3.12) indicate the presence of the interleaving effect. On the test of volume computation, the massed practice group answered 20% of the questions correctly, while the interleaved practice group answered 63% of the questions correctly.

The spacing effect and the interleaving effect both provide opportunities for an individual to engage in significant processing as a result of retrieval practice. The spacing effect allows for extended practice over time that leads to greater long-term memory strength, while the interleaving effect allows for comparative practice that leads to greater discrimination in long-term memory. For example, a veterinary student would benefit from distributing their studying across days and weeks, rather than cramming for an exam or surgery. In addition, their knowledge will get stronger as they see more and more clients, necessitating them to naturally activate relevant knowledge over time. Beyond developing strong memories, if they need to learn to differentiate, learning the normal anatomy of multiple species within one semester will allow students to differentiate anatomical features better than if they learn about each individual species in separate courses throughout the curriculum.

E. Enactment Effect and Production Effect

The enactment effect and production effect both involve engagement by the learner that involves some level of physicality. The ***enactment effect*** indicates that learning is enhanced when an individual physically performs an action associated with information, especially in contrast to only reading the information (Asher 1964; Engelkamp and Krumnacker 1980; Engelkamp 1998). This performative action may be engaging in a whole behavior (e.g., completing a lab experiment, conducting a physical exam, assisting in a surgery), performing the action described by a word (e.g., palpating, otoscopy, intubation), or gesturing (e.g., tapping on the location of a muscle or bone on a live animal while discussing the muscle or bone). The basis of the enactment effect is not entirely certain, although the evidence leans toward multimodal encoding, using multiple sensory and cognitive modalities to engage in information (i.e., visual, auditory, kinesthetic), and embodied cognition, the idea that our cognitive and physical processes are intimately intertwined and mutually contributory (e.g., situated learning, multisensory experiences; Engelkamp 1998; Lakoff and Johnson 1980; Madan and Singhal 2012).

For example, Silva et al. (2015), examined the enactment effect in younger adults and older adults under two conditions, actually engaging in a task (SPT – subject-performed task) or only reading a description of the task (VT – verbal only task). Specifically, 32 action–object sentences were created and written on note cards (e.g., break the toothpick, throw the dice). Participants were shown each sentence card along with the object on the card, one at a time. Participants either performed the action on the card with the object (SPT) or simply read the action–object sentence (VT). Of the 32 action–object sentence cards, each participant enacted 16 (SPT) and read 16 (VT). Following the presentation of all of the action–object sentence cards, participants were asked to recall as many of the action–object sentences as possible. The results of Silva et al.'s experiment (see Figure 3.13) indicate the presence of the enactment effect. For both younger adults and older adults, more of the subject-performed (SPT) action–object sentences were recalled than the verbal only (VT) action–object sentences.

Considering reviews and meta-analyses of the enactment effect, Roberts et al. (2022), focused on how enactment (SPT) compared to watching others perform a task (VT), imagining the completion of a task, and reading or hearing words or descriptions related to tasks. Overall, Roberts et al. found a large effect for the enactment effect. When considering moderating effects, Roberts et al. found that enactment had a large effect on memory and performance when compared to verbal tasks, and a medium effect when compared to watching others engage in the task. So, while reading/hearing about a task or watching others complete a task can improve one's memory and performance related to the task, engaging in the task itself produces significantly greater memory and performance. In addition, enactment has been demonstrated to positively impact memory and performance, whether the recall or performance was immediate or delayed.

While the enactment effect examines the impact of larger-scale physical performances on memory and performance, the production effect examines most smaller physical performances. The ***production effect*** indicates that information that is read aloud is remembered better than

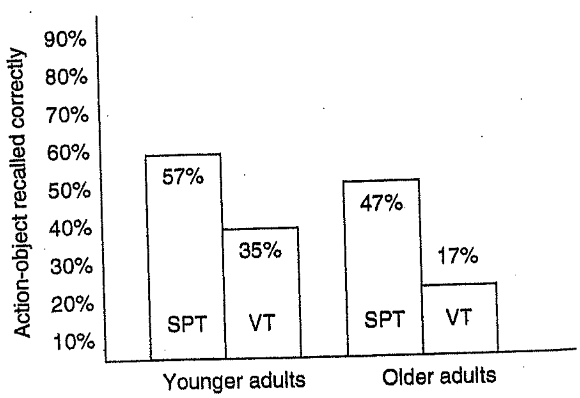


Figure 3.13 Mean correct action–object sentences recalled (e.g., roll the dice) for both younger adults and older adults in both the subject-performed task (SPT) and the verbal only task (VT). *Source:* Original figure, adapted from data reported in Silva et al. (2015). Copyright 2015 CC BY 4.0.

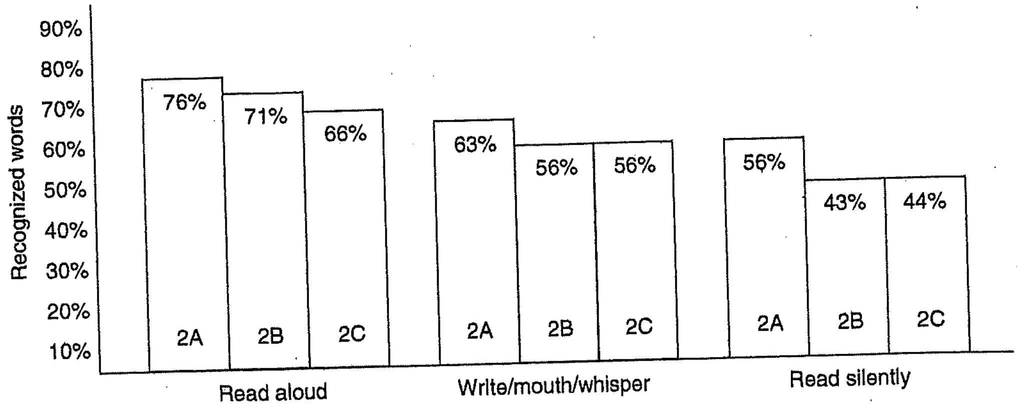


Figure 3.14 Mean correct test performance for students in Experiment 2A (Read Aloud, Write Words, Read Silently), Experiment 2B (Read Aloud, Mouth Silently, Read Silently), and Experiment 2C (Read Aloud, Whisper, Read Silently). *Source:* Original figure, adapted from data reported in Forrin et al. (2012). Copyright 2012 by the Psychonomic Society.

when information is read silently (Fawcett et al. 2022b; Forrin et al. 2012; MacLeod et al. 2010). This reading aloud over reading silently finding has also been extended to studies indicating that writing, typing, drawing, and spelling words or phrases can lead to better learning than simply reading (MacLeod and Bodner 2017). The theoretical foundation for the production effect has been hypothesized as resulting from (i) the read aloud words or phrases becoming "distinctive" against a background of read silently words or phrases or "distinctive" based on the sensorimotor features created during reading aloud (MacLeod et al. 2010), (ii) the read aloud words or phrase becoming more familiar than the read silently words or phrases (Fawcett and Ozubko 2016), or (iii) the read aloud words or phrases becoming more meaningful as they are processed semantically during speech (Fawcett et al. 2022b). It is perhaps most plausible that the production effect is a combination of the three approaches – distinctiveness, familiarity, and semantics – and not dependent on a single process (see Fawcett et al. 2022b).

For example, Forrin et al. (2012, Experiment 2), examined the production effect in relation to reading material aloud, reading material silently, or writing, mouthing (silently), or whispering the material. Specifically, across three experiments (2A, 2B, 2C) students were presented with 90 words, randomly ordered, in one of three colors (blue, white, red) and were told to read aloud the blue words, read silently the white words, and write (Experiment 2A), mouth (Experiment 2B), or whisper (Experiment 2C) the red words. After processing the words, students completed a recognition test where they were presented with 180 words, 30 words they had read aloud, 30 words they had read silently, 30 words they had written, mouthed, or whispered, depending upon the experiment, and 90 new words. The results of Forrin et al.'s Experiment 2 (see Figure 3.14) indicate the presence of the production effect. Across all three experiments (2A, 2B, 2C), students in the read aloud condition recognized the most words, while students in the read silently condition recognized the least words. Students in the write, mouth, or whisper conditions recognized an intermediate number of words.

Unfortunately, there are currently no meta-analyses examining the impact of production versus only reading (the classic production effect). Fawcett (2013, see also Fawcett et al. 2022a), however, conducted a meta-analysis examining the effect of production between two design approaches: within-subject designs versus between-subject designs. Specifically, the production effect is typically examined using a within-subject design where participants read some words silently and some words aloud, and their remembrance of the silent versus aloud words demonstrates the production effect (aloud words are remembered better than silent words; e.g., Forrin et al. 2012). Early research using a between-subject approach, when one group engages in only reading silently and another group engages in only reading aloud, resulted in no production effect (Dodson and Schacter 2001) and (seemingly) indicating that distinctiveness requires a background (reading silently) against which information becomes noticeable (reading aloud). However, more recent empirical research has demonstrated the presence of between-subject production effects, but at a much lower effect size than within-subject production effect (this finding that between-subject effects are significantly lower than within-subject effects is also evident in the enactment effect literature). Therefore, Fawcett's (2013) meta-analysis' findings of a small-to-medium between-subject production effect are likely indicative of a much larger within-subject production effect, although that analysis had not yet been conducted and published in the literature.

The enactment and production effects involve the fostering of learning through physical engagement, beyond the solely cognitive. These physical approaches can be extremely powerful, especially when combined with more traditional cognitive processing. Being a veterinarian requires a balance of cognitive and physical skills, and encoding specificity and transfer-appropriate processing, along with working memory-based processing, all of which support the use of cognitive + physical enactment and production. Students' learning is enhanced when they "do" and when they talk about the doing.

F. Zooming Out on Fostering Deep and Flexible Knowledge

It is essential to keep in mind our mantra – *what we process we learn*. As indicated previously, processing is neither neat nor tidy. This messiness is evident in the effects just discussed. None of these effects are "process pure," relying on only one or two processes neatly arranged and highly predictive. To be sure, each of these effects involves a diverse set of overlapping and intermixed processes. A veterinary student watching, listening, and assisting a veterinarian in fixing a calf's broken limb will involve retrieval (of prior knowledge regarding bovine anatomy and physiology), elaboration (of the new experiences with the aforementioned prior knowledge), generation (of new calf treatment procedures and behaviors), enactment (of the immobilization and splinting, not simply reading about it), and production (of ongoing comments, questions, and actions). Thus, fostering deep and flexible knowledge involves the making of informed and proactive decisions related to instructional actions and *not* the search for the "best" processing-inducing strategy or activity. For the veterinarian fixing the calf's broken limb, instructionally it would make sense for the veterinarian to (i) verbalize their planning, attention, ongoing actions, and decision-making processes, (ii) ask the student predictive and explanatory questions, and (iii) engage the student in as much of the procedure as possible, without sacrificing the care of the animal. Is this the only way to make this experience educational for the student? Definitely not. The challenge is to make these instructional decisions in an informed and proactive manner for the betterment of the animal, the student, and the profession.

Also, returning to where we started, the idea of "it depends" must be taken seriously. While the previous findings and effects have been discussed with supporting literature and examples, for each of the effects there is literature that finds no effects or even negative effects. These contrary findings do not negate the findings themselves, but rather, they remind us that these effects are not laws that always work for all students, under all conditions. It is common in real-world, real-time educational environments for specific strategies, applied in specific courses, with specific content and students, not to work. Why? It depends. All of the effects mentioned have boundary conditions under which they no longer seem to apply. Making informed and proactive instructional decisions is more like dealing with an elusive internal medicine case than vaccinating a happy, healthy puppy.

Part 4: Implications of Memory and Cognition for Learning

This chapter provides the foundation for understanding the concept of active learning. **Active learning**, while having no formal or agreed-upon definition, focuses on the students' processing of their knowledge and experiences for the purpose of meaningful learning. While Freeman et al. (2014), and Theobald et al. (2020), both provide evidence that engaging students in active learning leads to increased learning, Bernstein (2018) laments that not enough specific guidance is provided to instructors. Hopefully, this chapter and the implications below provide some of that guidance.

A. Students' Learning Is a Function of Meaning Making

To do, to think, to understand, to solve, to evaluate, to interpret, to reason, to apply . . . all require that one first makes meaning. The making of meaning necessitates connecting new knowledge to prior knowledge (meaningful learning) and wrapping prior knowledge around the new knowledge (elaborative learning). In addition, to increase the level of meaning making, new knowledge should be integrated into existing knowledge structures (i.e., schemas, scripts, concepts, procedures) through the application of knowledge and experience to problems.

Learning without meaning (rote learning) results in weak, disconnected, and poorly applicable knowledge, which can lead to inert knowledge. *Inert knowledge*, knowledge that one possesses but cannot use, can result from a lack of context (learning without an understanding of its relevance), rote learning (learning through meaningless repetition), fragmented knowledge (learning without connections to existing knowledge), lack of practice (learning without opportunities to apply knowledge in various context and for various purposes), and a lack of awareness and control of knowledge (learning without an understanding of how and when to apply the knowledge). Rote learning tends to result in more forgetting, less inferencing, and less usefulness in applying the knowledge to new situations.

To encourage meaningful learning, veterinary students' education should include:

1) Providing meaningful contexts and real-world applications of the knowledge and experiences students develop during their education.

2) Encouraging the development of deep learning, critical thinking, and integrated understandings of the underlying concepts that make the knowledge meaningful and useful.
3) Helping students make connections between conceptual and procedural knowledge, promoting the simultaneous organization and usefulness of their knowledge and skills.
4) Engaging students in multiple opportunities to practice and explain their knowledge and skills under varying conditions.
5) Fostering an understanding of what they know, including when, why, and how to leverage their knowledge and skills for the attainment of goals through reflection, self-assessment, and self-regulation.

B. Students' Learning Is Fostered by Their Active Processing of Knowledge and Experience

Learning, the making of meaning, and the application of knowledge entail that students engage in the active processing of their knowledge and skills. Processing covers a wide spectrum of engagement, including perceiving one's environment; attending to relevant aspects of the environment (including one's internal environment); connecting and integrating the objects of one's attention with one's prior knowledge; organizing, integrating, and synthesizing this experience and meaningful knowledge; and applying this knowledge and understanding to current situations, problems, or goals.

Processing is the proximal cause of learning: no processing, no learning. Processing may take many forms, including the conscious and proactive focusing of attention, the deliberate connecting of new and prior knowledge, and the intentional engagement of specific cognitive and behavioral strategies. While processing is not directly observable, its effects are – learning and performance. When a veterinary student engages in self-questioning, creates their own summaries of lectures, explains their understandings of physiological functions to peers, or thinks through the symptoms of diseases while driving to campus, their learning improves. When a veterinary student practices otoscopy on a model or live animal, engages in a client consultation in a clinic setting, or performs a spay under the direction of a veterinarian, their performance improves.

To motivate effective processing, veterinary students should be encouraged to:

1) Engage in deeper, more meaningful processing of new information, and actively make connections between new and prior knowledge (elaboration effect).
2) Recall knowledge and skills from memory, rather than simply rereading or restudying the information (retrieval effect).
3) Generate knowledge and skills themselves, rather than passively memorizing the knowledge and skills from readings or presentations (generation effect).
4) Engage in formal and informal study and practice sessions that are distributed over time, rather than crammed into a single session just prior to an assessment or activity (spacing effect).
5) Alternate between topics under study, especially when the topics have similarities that might be confusing, rather than focusing on just one topic at a time (interleaving effect).
6) Perform physical actions related to new knowledge and skills, rather than simply observing the actions of others or reading about them (enactment effect).

C. Students' Learning Is Constrained by Their Processing Limitations

The human memory system is replete with "bottlenecks" that constrain processing. First, while the human body may sense many sounds, sights, smells, tastes, and touches, it may only perceive, or attend to, a few. Second, the human memory system can only maintain simultaneous activation of a few short-term memories and process a limited amount of information in working memory. Unfortunately, split-attention (a form of multitasking) and high cognitive load have been associated with decreased performance, decreased comprehension, slower task completion, and higher error rates.

With extensive practice and the cunning use of strategies, individuals can mitigate some of the negative impacts of human information processing limitations. Some of these include:

1) *Chunking*. Grouping information into smaller meaningful clusters allows one's memory to operate on the whole chunk or cluster, rather than the smaller individual components, decreasing cognitive load and increasing working memory functioning.
2) *Practice*. Practicing leads to increased efficiency and accuracy in activating knowledge (declarative knowledge) or performing skills (procedural knowledge), as well as the conversion of step-by-step actions into automated skills.
3) *Organization*. Increasing levels of knowledge organization, such as schemas, scripts, and concepts, as well as proceduralized actions, leads to increased efficiency in knowledge access and decreased cognitive load in knowledge processing.
4) *Prioritization*. Focusing on the most critical knowledge and skills, consciously and proactively, will reduce the likelihood of becoming distracted or engaging in multitasking.

5) *Simplification.* Breaking complex knowledge and skills into component parts, especially when one is a novice, will lead to increased organization and decreased cognitive load.
6) *Offloading.* Using external resources to "store" needed knowledge – checklists, Post-It notes, visual aids (charts, diagrams), and voice memos – leads to increased decision-making and decreased cognitive load.
7) *Breaks.* Taking short breaks that include light exercise or routine mental distractions that require a low, but not zero, level of attention (e.g., driving, walking, crossword puzzles, reading news) can help to prevent mental fatigue, improve cognitive function, improve attentional focus, and improve creative thought.

D. Students' Learning Is Facilitated by Instructional Strategies that Encourage Processing

In pursuit of cognitive processing focused on meaning making, instructional strategies provide an effective mechanism for motivating student engagement. That said, understanding the relationship between strategies, processing, and learning is essential. Specifically, the goal of strategy use is to motivate students to engage in cognitive processing that is focused on learning: strategy → processing → learning. These instructional strategies may be formal or informal (cooperative learning versus casual pre-class conversation), large or small (problem-based learning versus think-pair-share), or resource-intensive or resource-efficient (design-based problem-solving versus small-group discussion). The focus on processing is key as instructional strategies are often undertaken with the assumption that the strategies themselves will lead directly to learning, they do not. In using an instructional strategy, instructors must be mindful of how the strategy is employed so that the strategy leads to processing.

For example, the *think–pair–share* strategy involves (i) instructors asking a question or providing a problem, (ii) students thinking about a response or solution to the question or problem, and (iii) students discussing their responses or solutions with other students. The strategy itself is fairly straightforward, but how the strategy is implemented determines its usefulness in fostering learning. If the instructor asks a yes/no question, then the students will have little to think about or discuss. If the instructor asks a question that is too easy or too hard, students will be unwilling or unable to respond adequately. If the instructor asks a question that is deemed irrelevant or trivial by the students, they will be unmotivated to give it much thought. A good think–pair–share question is (i) open-ended, encouraging multiple perspectives or solutions, (ii) higher-order, involving the application of knowledge or the consideration of multiple knowledge sources, (iii) relevant, connecting to the current discussion, class, or course, and (iv) appropriate, challenging for the students but attainable. After a suitable think–pair–share question is asked, there needs to be a sufficient "wait time" for students to process the question, consider various answers, make decisions, and formulate a response. Finally, students must be provided the time and impetus to share their own thoughts and conclusions, as well as listen to and respond to their partner's thoughts and conclusions. Processing, or the reason for the strategy and the cause of the learning, takes time. Two or three minutes of silence will seem like a long time in the middle of class, but this time is necessary for students to process and signals to the student that their responses should be well thought out and not off-the-cuff. To further foster processing, instructors should provide directions as to how students should "share." For example, "Explain your diagnosis and treatment to your partner, and if you're the partner, provide some feedback on the appropriateness of their response. Then, switch roles." Again, it is important that the students are provided with sufficient time to discuss.

E. Students' Learning Is Subject to Individual Differences in Knowledge, Experience, and Processing

Students are not widgets and do not all respond similarly to the same instruction or instructional materials. Students with little veterinary knowledge and experience will need more time, examples, and explanations to begin the process of building conceptual knowledge and engaging in procedural knowledge. In addition, they will tend to respond slowly, with poorly integrated knowledge and error-prone procedures. Everyone begins their veterinary careers as novices, constructing meaning and understanding over time with experience and feedback. With continued class, project, lab, and clinical experiences fostering real-world, complex processing, students will develop integrated knowledge structures and automated skills. Novices become experts as they process their knowledge and experience across a multitude of classes, discussions, readings, clients, and animal interactions, procedures, and surgeries, including successes and failures. **There is no shortcut to expertise.**

Summary

It seems appropriate to end where we started, searching for meaning through processing that depends on the individual, the experience, and the goals for learning. Applying the principles of learning and integrating the elaboration, retrieval, generation, spacing, interleaving, enactment, and production effects into instruction can result in deep and flexible knowledge and performance. Ultimately, the concepts addressed in this chapter provide a rationale for how and why learning occurs, as well as guidance for effective teaching.

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