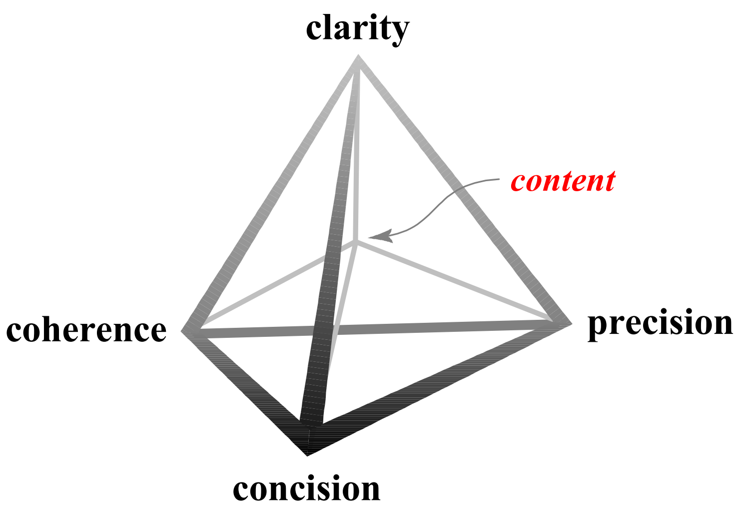
Communicating Science

an introductory guide for conveying scientific information to academic and public audiences



Roy Jensen

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Communicating Science

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Communicating Science is an introductory communication guide that provides students with a foundation for writing, reviewing, and presenting technical information. Chapter 3 (Fundamentals of learning) introduces the constructivist learning model and presents the current understanding of how people learn, how learning changes with increasing knowledge about the subject, and presents strategies for effective teaching and learning.

Understanding the learning process benefits both the learner and the instructor. To facilitate this understanding, Chapter 3 of *Communicating Science* is available for free, subject to the conditions below.

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Chapter 3. Fundamentals of learning

> Communication is most effective when both the sender and receiver (writer & reader, speaker & audience) are engaged in communicating and in learning.

In order to prepare quality documents and give quality presentations, it is valuable to have an understanding of how people learn. This chapter presents some of the psychological and pedagogical theories that underlie effective learning and effective instruction.*

Table 3.1 Common and scientific definitions of *knowledge* and *learning*.

Common definition	Scientific definition
Knowledge consists of the accumulated facts and impressions we retain from previous experiences.	***Knowledge*** exists as neural networks in the brain.
Learning is the process of increasing knowledge and/or skill.	***Learning*** occurs when new connections are formed between neurons, expanding the neural network.

Knowledge is gained and shared through communication. Clear, coherent, concise, and precise communication facilitates effective and efficient knowledge transfer and learning by others.

> Tell me and I will forget; show me and I may remember;
> involve me and I will understand. — Chinese proverb

Knowing how people learn is of profound interest and importance. The better we — individuals, instructors, employers, and society — know how people learn, the better we can design and present information in modes that facilitate learning. There is no single "correct" way to present information. Learning is an individual process: what is effective for one learner may not be for another. Furthermore, it is valuable for instructors and learners to know how people learn as it allows them to optimize their own learning and better accept the diverse instructional strategies used by instructors.

Figure 3.1 presents a visual overview of the major concepts presented in this chapter.

* These theories approach the same concept — learning — from different perspectives. Some theories use different terminology, and some terms were changed to maintain consistency throughout this chapter.

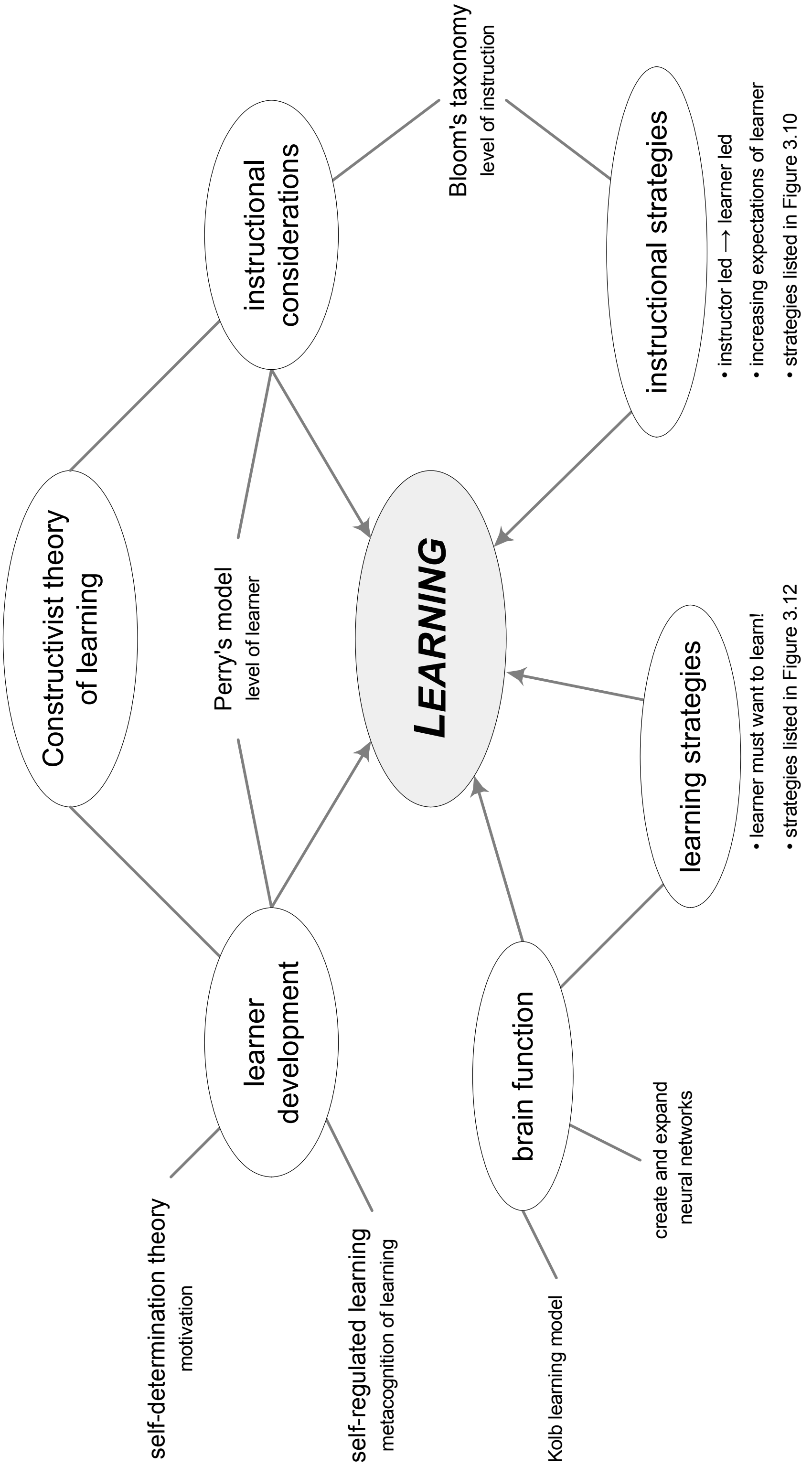


Figure 3.1 An overview of the concepts presented in this chapter.

3.1 Learning theories

There are several theories of how learning occurs, with educational psychology actively testing and refining the theories and determining their range of application.

Constructivist theory

In academic environments, the *constructivist theory* is most applicable. The ***constructivist theory*** proposes that learning occurs when new experiences and new information integrates into our existing knowledge framework, thereby expanding the framework. While originally an empirical proposal, brain-function research has provided a biophysical foundation supporting the constructivist theory.

To effectively teach a concept, an instructor must ensure the information being presented overlaps with the learners existing knowledge. This often takes the form of solving real-world problems and using learned equations to derive more complex mathematical equations. If there is no overlap, the new information is not retained and no learning occurs.

To effectively learn a concept, a learner must be willing to learn, have a connection with the concepts being presented, and take an active role in learning. Figure 3.2 shows that the more active a learner is in their environment, the more they learn.

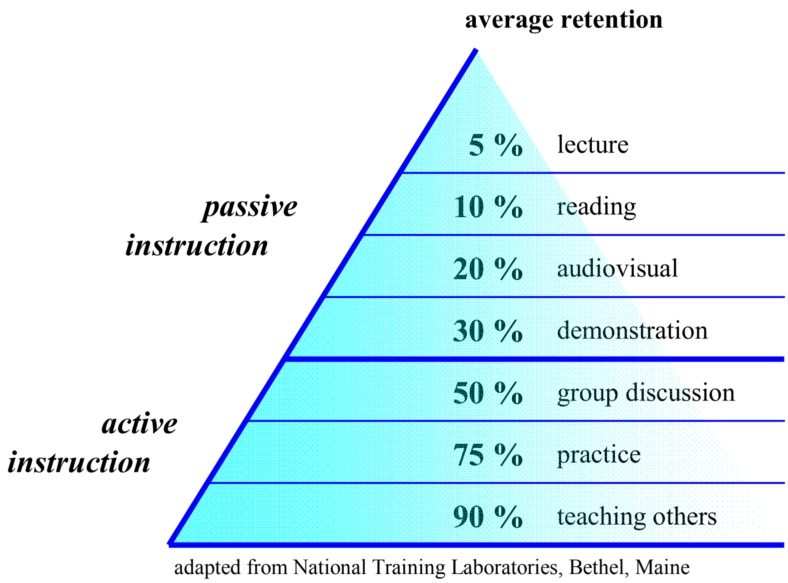


Figure 3.2 Information retention as a function of selected instructional strategy. A larger list of instructional strategies is presented in Figure 3.11.

Self-determination theory

Self-determination theory explores the foundations underlying motivation and personality. The theory proposes that people have three universal needs:

- *competence*: the need to possess knowledge and skills
- *relatedness*: the need to associate and interact with others
- *autonomy*: the need to have control over their life

When these needs are supported, a learner attains increasing senses of well-being and initiative. Social and cultural environments can have beneficial or detrimental effects on attaining these needs. Motivation also affects the attainment of these needs. There are two types of motivation:

- *intrinsic motivation* exists when a learner chooses to learn out of an internal interest in the concept. These learners take on tasks because of their personal interest in the task, the inherent challenge, and the satisfaction they derive from completing the task.
- *extrinsic motivation* exists when a learner chooses to learn because of an external factor, such as the achievement of a grade, imposed deadlines, fear of discipline, entrance into medical school, getting on the honor roll, etc.

In general, intrinsic motivators tend to increase the attainment of the universal needs, while extrinsic motivators either neutrally affect or are detrimental to the attainment of these needs.

For any given learning opportunity, a learner has both intrinsic and extrinsic motivators, and the number of each motivator may change during the learning process. Additionally, extrinsic motivators can change into intrinsic motivators.

Intrinsic motivation is *increased* by

- the content having relevance to the learner and/or society
- having instructors perceived as caring
- learner engagement (active instructional strategies)
- receiving positive feedback on work

Intrinsic motivation is *decreased* by

- having tasks that are too challenging or too simple
- generic, non-contextual problems
- excessively stressful environments
- receiving false praise

> Learners often initially choose a university major because of an extrinsic motivator, “I’m going to be an engineer/lawyer/physician/ etc. like my <close family member>.” Learners often change their major to something they are intrinsically interested in.
>
> Many of you — people reading this right now — had a career path planned out, and you now have doubts. This is normal! Many subjects are not taught in high school, so a university course in anthropology, biochemistry, psychology, sociology, and other subjects is your first exposure to these disciplines, and you may fall in love with them. This love is the heart of intrinsic motivation.

To optimize success in learning, learners must maximize intrinsic motivators. They must decide they want to learn for the pleasure and challenge of learning new material. A goal of instructors is to gauge the level of the learners and set challenging but attainable outcomes and assessments. For any given assessment, some learners may find the exercise easy and others may find the exercise challenging. This is the nature of diverse learners. Instructors provide supplemental resources for struggling learners, and encourage advanced learners to challenge themselves with more challenging problems, including directing them to other courses and research opportunities.

To look closer at the idea of extrinsic and intrinsic motivators, consider deadlines. Imagine being well into your career and being asked to write a book on your work. A deadline is set for the drafts and the final version of the book. Early in the writing project, these deadlines are extrinsic motivators, “must get the book done by the deadline”. However, as the book comes together and you receive positive feedback, the deadlines become more of a goal — to have the book done so that it becomes available to the world. The deadline is now an intrinsic motivator and boosts your competence, relatedness, and autonomy.

Self-regulated learning

Related to self-determination theory is the idea of ***self-regulated learning***, which is a strategy for learners to actively control their thoughts, behaviors, and emotions so they focus on and optimize their learning. Self-regulated learners have a high degree of *metacognition* (thinking about their own thought processes). The learning process can be divided into three stages. A learner is expected to

1. *prepare*: identify what learning needs to occur, set a plan and timetable to complete the learning, and establish an emotional state where the learner wants to learn
2. *perform*: have the self-discipline to focus on task, monitor their successes and struggles, and adapt their learning strategies to more effectively and efficiently learn
3. *reflect*: review their performance after completing the task, identify factors that reduced performance, and modify their learning strategies for future learning opportunities

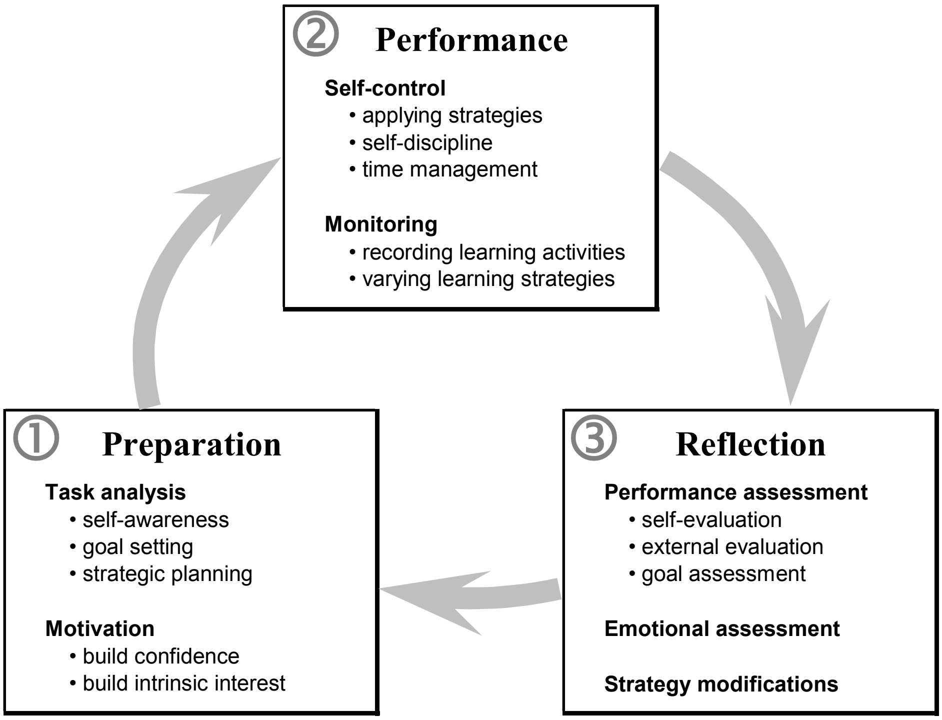


Figure 3.3 Metacognitive stages that a learner should cycle through to optimize learning.

Source: adapted from Zimmerman BJ. Becoming a self-regulated learner: An overview. Theory Into Practice. 2002;41:64–70.

A highly self-regulated learner learns quicker, more efficiently, and better understands the material. This learner does better academically, has a better opinion about learning, and is generally more successful in their career, where independent life-long learning is expected.

Becoming a self-regulated learner is itself a learned activity. Discovering that a person does not learn effectively often begins with poor performance or failure. For example, first-year university students were often not challenged in high school and never learned how to effectively and efficiently learn and study. First-year post-secondary is challenging because of the faster paced material, greater academic expectations, greater student independence, and the lack of effective learning skills.

Self-regulation is a semi-conscious process. A low self-regulated learner is *impulsive* and easily distracted from learning. They will abandon learning when a more enjoyable activity is available: food, television, surfing the internet, a night out with friends, etc. A high self-regulated learner is *dedicated*, and knowingly focuses on learning despite other more-interesting opportunities. They review what they learned daily, begin homework when it is assigned, and have term projects done early so they can review and revise them before submission.

Low and high self-regulated learners exhibit differences in their perceptions on the difficulty of material and in their learning strategies.

- Low self-regulated learners tend to bypass the *preparation* stage and begin at the *performance* stage. When they struggle to learn new information, they tend to blame their lack of ability rather than attempting alternative learning strategies, and they often abandon the learning activity.
    - "I dropped <course> because I'm not good at it."
    - "I don't like <subject/instructor>."
- High self-regulated learners, when they find themselves struggling, change their learning strategy.
    - "Well, this isn't working. Let's try <a different strategy>."

  These learners monitor their learning at multiple levels. They apply Figure 3.3 to individual exercises within a problem set and to the entire problem set within the context of the course.

An instructor can help learners develop their self-regulation ability by modeling and facilitating self-regulation. However, it is up to the learner to attempt and identify strategies that facilitate their learning, increase their confidence, build self-efficacy, and build intrinsic motivation. These practices will also cause the learner to look at to future learning tasks as *opportunities*, not *chores*.

3.2 Learning and the brain

Brain function research is a very active field. The development of real-time MRI has provided researchers with a powerful tool to explore structure-function and activity-function relationships within the brain.

The brain is composed primarily of neurons, which are cells responsible for processing, transmitting, and storing information. Neurons contain

- *dendrites*, which receive signals from other neurons
- an *axon*, which propagates signals within a neuron
- *synaptic terminals*, which transmit signals to other neurons

The *synapse* is the region between a synaptic terminal on one neuron and a dendrite on another. It is still not well understood how a neuron knows which neuron it is receiving a signal from or how it selects which neuron to transmit the signal to. It is known that *learning* is the formation of connections between neurons, which leads to the development and expansion of *neural networks*.

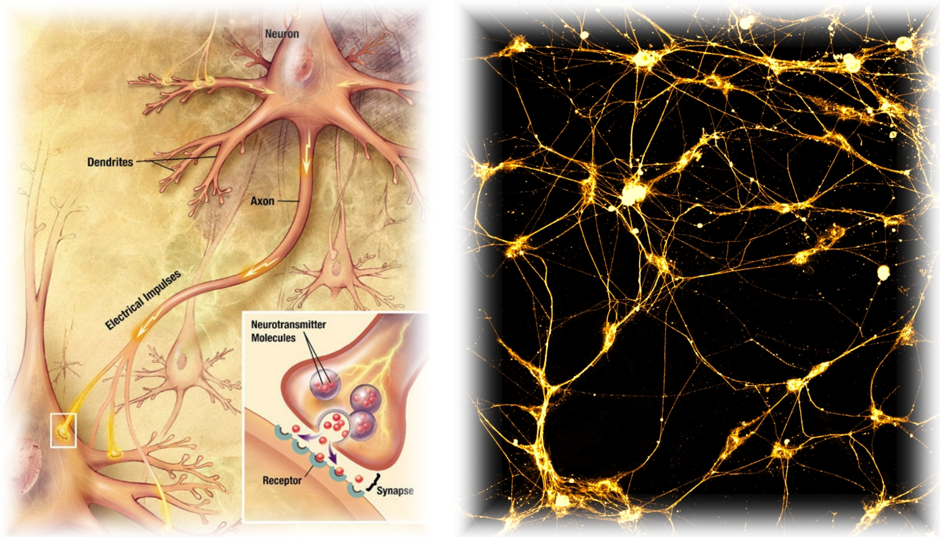


Figure 3.4 (left) An artists conception of the propagation of neural impulses.
(right) An image of a real neural network, created by adding a fluorescent dye to nerve cells.

Source: *left*: public domain; *right*: Lovelace M, Chan-Ling T, Armati P, Chow R. University of Sydney, Sydney, NSW, Australia.

Kolb's learning model

Dr. David Kolb is an educational theorist at Case Western Reserve University. In 1985, he developed a model for how people learn. Kolb proposes that a person cycles through four stages when learning:

- abstract hypothesis (planning)
- active testing (experimentation)
- concrete experience (observation)
- reflective observation (review and analysis)

Dr. James Zull, a biologist also at Case Western Reserve University, discovered a link between Kolb's model and the regions and pathways in the brain. Zull's work provides a biophysical foundation for Kolb's model, which is presented in Figure 3.5.

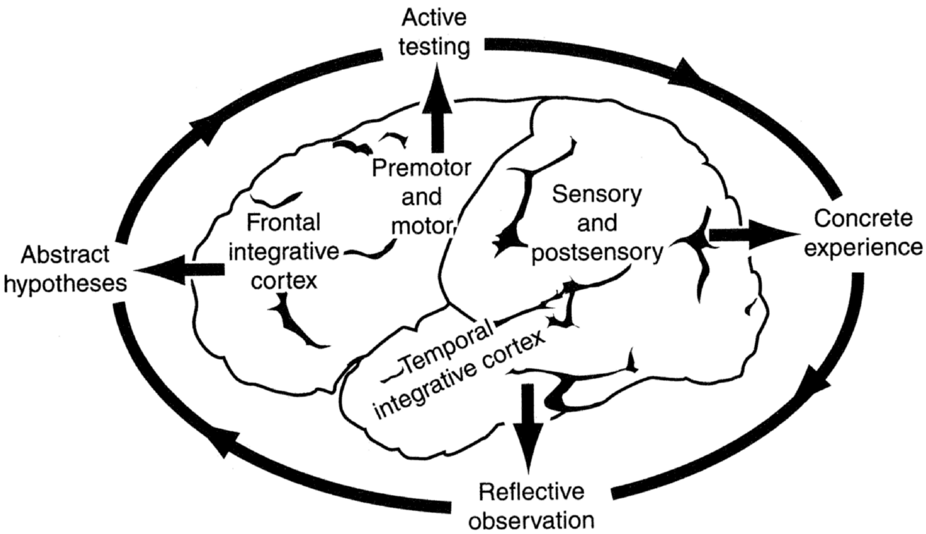


Figure 3.5 The relationship between Kolb's learning model and functional regions in the brain. (Used with permission from Dr. James Zull.)

The regions of the brain have functions that match the learning stages proposed by Kolb.

- The *frontal cortex* is responsible for high-level reasoning.
- The *premotor and motor* region is responsible for coordinating and controlling the body.
- The *sensory and post-sensory* region receives input from the senses and processes that information to develop an understanding of the surroundings.
- The *temporal cortex* is responsible for long-term memory storage.

A person cycles through all of the stages as they learn. However, most people prefer one stage more than the others.

Kolb also proposed learning styles as the transition between the stages.

- *converging*: abstract hypothesis → active testing
- *accommodating*: active testing → concrete experience
- *diverging*: concrete experience → reflective observation
- *assimilating*: reflective observation → abstract hypothesis

Figure 3.6 illustrates the four learning stages and four learning styles. Assessments are available for people to determine and visualize their preferred learning stage(s) and style(s).

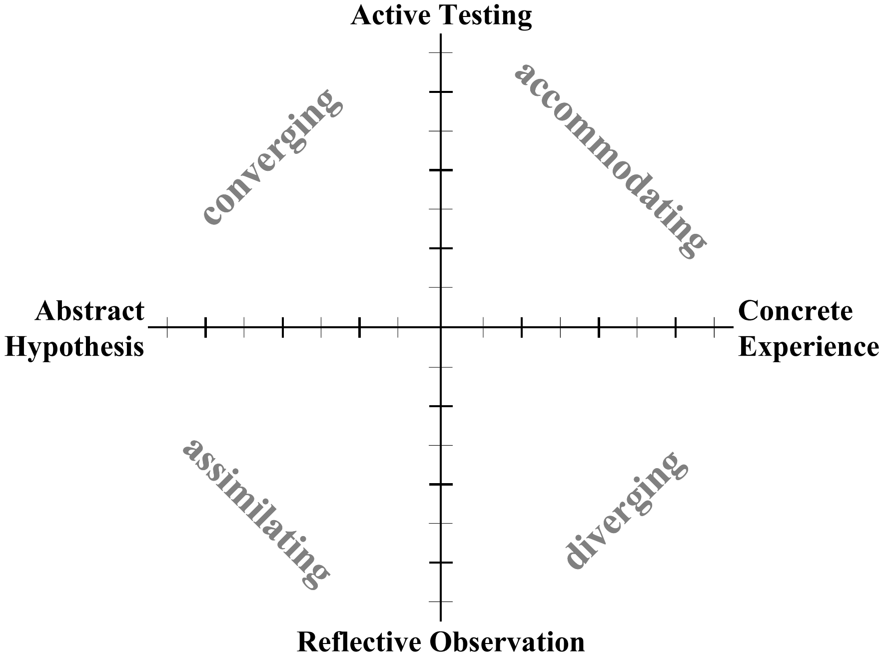


Figure 3.6 The four learning stages (on the axes) and four learning styles (in each quadrant) proposed by Kolb.

The *converging* style involves applying theories to solve problems and find solutions to practical issues. (Persons who prefer this learning style commonly have careers in engineering, medicine, economics, and applied science.)

The *accommodating* style involves adapting to the immediate circumstances. People rely primarily on intuition instead of logic to solve problems. (Common careers include management, education, sales, and nursing.)

The *diverging* style involves looking at things from different perspectives. People watch rather than do and tend to gather information and generate ideas (brainstorm) to solve a problem. (Common careers include social work, acting, literature, and journalism.)

The *assimilating* style involves taking a concise, logical approach to solving a problem. People take information and organize it logically, focusing on ideas and abstract concepts. (Common careers include science, mathematics, and law.)

> The previous pages list careers of people who prefer a given learning style, but these people must be functional in all the learning styles to be good in their career. *Practice* is required to become comfortable at all four learning styles. This practice can be in the form of a hobby: scientists who exercise and socialize develop their accommodative and divergent learning styles.
>
> Adept learners are comfortable in all four learning stages.
>
> Weakness at any stage introduces barriers to learning.

Learning

At birth, the brain has rudimentary neural networks to perform basic functions: breathing and circulation. Everything else is learned: muscle control, language, social interaction, etc. For example, an infant has very limited voluntary muscle control. Through random activation of neural pathways, an infant learns to suckle and move their fingers, arms, legs, and other parts of their body. If the neural pathway leads to a productive motion (suckling to receive milk, for example), the motion is repeated and the neural pathway reinforced. If the neural pathway is non-productive (a movement that causes pain, for example), the pathway is not used again and degenerates. As the neural networks develop and expand, the baby learns increasingly complex tasks: grasping, crawling, walking, eating, talking, etc. These abilities are refined through repeated use. (For example, athletes train to have highly refined movements.)

To see the Kolb cycle applied, envision an infant wanting to grab a toy:

1. The infant hypothesizes that, by extending their arm, they can reach and grab the toy.
2. The motor cortex is activated to extend the arm.
3. The sensory cortex receives input from both the eyes and hand; the eyes see the hand extend and miss the toy; the nerves in the hand signal that it did not grab the toy.

4. The temporal cortex determines that the hand did not extend far enough, missing the toy.
5. The infant hypothesizes that by extending their hand further, they can reach the toy.
6. … the cycle repeats …

Learning is a process. The first exposure to new information or to a new action begins neural network development. Repeated use of the neural network strengthens the pathways. The more the pathways are used, the better the information or action is learned. Use also creates pathways to related information that further expands the neural network and increases knowledge. Technically, this process is called *long-term potentiation*. If unused, the pathway degenerates and knowledge is lost.

Consider:

- Watching baseball games does not mean you can hit a baseball.
- Watching an instructor solve a math problem does not mean you can solve one.
- Watching a nurse administer an IV does not mean you can do it.
- Reading a well-written novel does not make you a writer.

In each case, the professional — athlete, instructor, nurse, writer — completes the task with relative ease. These people have practiced these skills many, many times. They have developed extensive neural networks that activate when required. By watching their actions, you have started neural network development — the first step in the learning process. Practice is required and critical to become proficient at any task.

Experts think differently than novices

Psychological research has proposed that it takes an average of ten years for a person to become an expert in a field. This time is spent developing, expanding, and using the neural network. Novices struggle to identify the relevant information, struggle to identify the additional information they need to solve the problem, and struggle to determine a strategy to solve the problem. For experts, this linking and recall is automatic and natural. Novices develop and expand their neural networks as they successfully complete tasks. This increases their competence and confidence as they gain a deeper understanding of the field, eventually to the expert level.

The progression from novice to expert initially requires mentorship, with increasing independence as the novice gains experience and demonstrates skill.

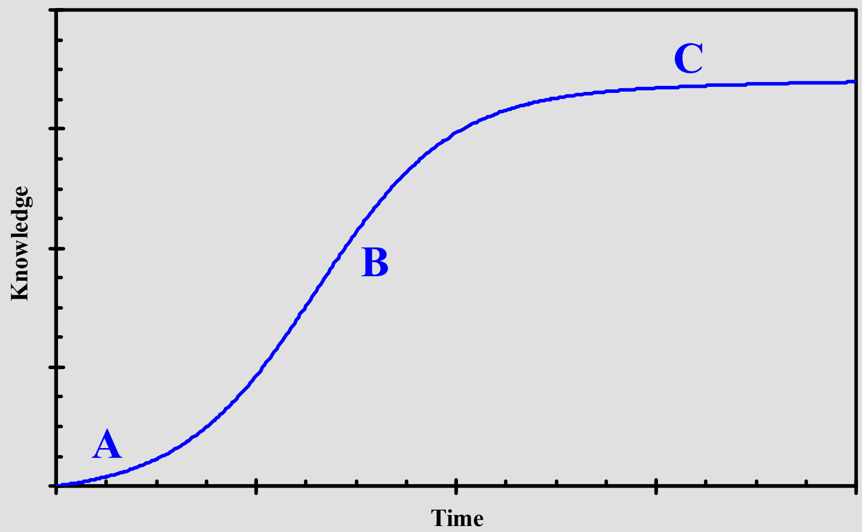


Figure 3.7 A typical learning curve. Initially at **A**, the novice learns slowly as foundational information is learned. At **B**, the learning rate increases as connections are made between concepts. At **C**, the expert continues to learn as they conduct research in the field and follow the contributions of other researchers to the field. The time required and knowledge acquired depends initially on the instruction by others and finally on the efforts of the learner.

Applying this to post-secondary instruction: professors typically teach material in a way that makes sense for them — how they understand the material. This may not be the best method as their understanding was developed after years of dedicated study, which the student has not completed and may not be interested in completing. It requires significant effort to produce instructional material that presents information in a way conducive to student learning. This is especially important when those students have diverse interests, like in first-year courses.

Figure 3.8 illustrates the progression of person from conducting laboratory experiments to conducting independent research, and how students typically progress in grade school (K-12), undergraduate, and graduate school.

A learner starts out being dependant on others to teach them (passive). With increasing knowledge and experience, a learner becomes increasingly independent, completing tasks with less and less guidance (guided). Ultimately, a person can function independently and makes decisions for themselves (self-directed).

	Instructor led (passive learner)	⟶ *Guided inquiry*	⟶	*Learner led* (self-directed learner)
Selecting a research question	Learner uses question posed by instructor.	Learner refines question posed by instructor.	Learner poses question based on information from instructor.	Learner poses question.
Procedure development	Learner given procedure.	Learner given framework for procedure.	Learner told what data is needed and develops procedure.	Learner identifies what data is needed and develops procedure.
Data collection	Learner is aided with data collection.	Learner sets up equipment and collects data with supervision.	Learner sets up equipment and collects data with minimal supervision.	Learner sets up equipment and collects data.
Data analysis	Learner given steps to analyze data.	Learner given framework for analyzing data.	Learner told what information is required and formulates strategy.	Learner formulates analysis strategy.
Data interpretation	Learner told connections to scientific knowledge.	Learner given possible links to scientific knowledge.	Learner directed toward areas and sources of scientific knowledge.	Learner independently identifies links to scientific knowledge.
Reporting	Learner answers questions posed by instructor.	Learner answers questions in report format.	Learner informed what areas to cover in report.	Learner independently prepares report.

grade school — *undergraduate education* — *graduate school*

Adapted from *Inquiry and the National Science Education Standards*, Table 2.6, National Academy Press, **2000**.

Figure 3.8 The progression from an instructor led to learner led environment while conducting laboratory work, from laboratory experiments to research projects.

Working and long-term memories

Psychology research proposes that the brain has a *working memory* that stores information relevant to solving the problem and a *long-term memory* that is the collection of our knowledge. A person can store between three and seven bits of information in their working memory. Recall from long-term memory is rapid, transparent, and limitless.

There has long been a debate amongst educational researchers about what needs to be memorized and what can just be looked up. For example, it was argued that, because of calculators, people did not need to memorize multiplication and division tables. In schools, memorization was devalued and calculators introduced much earlier. The long-term result: students are poorer at mathematics. The limited capacity of the working memory explains why. If memorized, the simple arithmetic results can be recalled from long-term memory to complete more complex mathematical problems. When not memorized, the simple arithmetic occupies some of the spaces in the working memory, increasing the challenge of solving the complex problem. Learners are less capable at mathematics and perceive it to be harder. (Yes, this is still a problem.)

To illustrate a growing neural network, consider the progression of learning and applying mathematics.

Learning numbers and to count
→ learning addition and subtraction
→ learning multiplication and division
→ learning that variables represent numbers
→ learning powers, exponents, and logarithms
→ learning geometry, trigonometry, and algebra
→ learning calculus
→ learning pure mathematics

A person cannot progress to the next level without having committed the current level to long-term memory. For example, learners need to have memorized the basic mathematical operations before they learn algebra because they need to be able to unconsciously apply these operations when manipulating algebraic functions. Similarly, algebra needs to be well understood before learning calculus. For another example, you learned about mathematical formulae in grades 7 and 8, and you applied them to simple problems in your mathematics and science courses. In subsequent grades, you manipulated these formulae and used increasingly complex formulae to solve more challenging problems.

3.3 Considerations when teaching and learning

Bloom's taxonomy

Bloom's taxonomy is a method of categorizing assessments and instructional activities. Bloom defined three learning domains:

- *cognitive domain*: working with information
- *affective domain*: working with emotions
- *psychomotor domain*: working with tools or instruments

Within each domain, there is a progression from simpler low-level activities to complex high-level activities. For every subject, a learner progresses through these levels as they learn the subject.

← level →			
high	create	characterize	naturalize
	evaluate	organize	articulate
	analyze	value	precision
	apply	respond	manipulate
	understand		
low	remember	receive	imitate
domain:	***COGNITIVE***	***AFFECTIVE***	***PSYCHOMOTOR***

Figure 3.9 Bloom's learning domains and the progression of learning activities within each domain.

For example, a grade 8 student who has just been introduced to algebra would not be able to solve Schrödinger's equation for a particle in a finite-depth well. Similarly, a grade 11 biology student who has just dissected a frog would not be able to remove someone's appendix. These learners must gain more knowledge and experience as they apply the knowledge to increasingly challenging tasks. With sufficient learning, they become competent at quantum mechanics and surgery, respectively.

Scientific research primarily develops the cognitive and psychomotor domains with the knowledge and skills you learn. The affective domain develops as you convey information to others, since you must consider the audience and the tone of the communication to successfully convey information to them. Figure 3.10 expands the cognitive domain and lists representative verbs used to construct assessments at these levels.

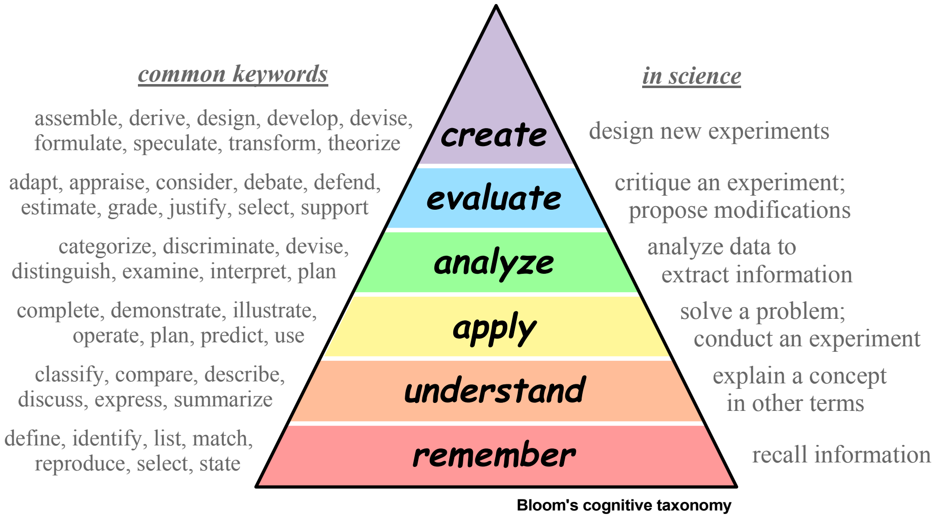


Figure 3.10 Expansion of Bloom's cognitive domain to illustrate the verbs used at each level and in application to conducting an experiment. Some verbs may be used in other categories, depending on the context of the question.

Clark* applied Bloom's taxonomy to instructional strategies. The results are presented in Figure 3.11. Effective teaching requires that the instructor and learner progress from lower-level to higher-level instruction. The lower-level instructional strategies tend to be passive (instructor-centered) while the higher-level strategies are active (student-centered). The highest level of instruction is *self-directed learning*, but without the commitment of the learner to learn on their own, they will never reach this level. That is, the learner must take personal interest and ownership in their learning. These people excel academically and in their careers. (Learner levels are presented on page 137.)

* Adapted from Clark D. Bloom's Taxonomy of Learning Domains [internet] [cited April 2014]. Available from www.nwlink.com/~donclark/hrd/strategy.html

← level →	INSTRUCTIONAL STRATEGIES
high	<*developed independently through self-directed learning*>
	on-the-job training, field and clinical work, hands-on activities (e.g., lab), peer instruction, independent study, individual projects, directed research, debates, recitations, competitions
	student-led problem solving, current events & applications, group projects, case studies, service learning, job shadowing, role-playing
	instructor-led problem solving, discussion, questioning, think-pair-share, reflection, role-playing, modeling, simulations, guest speakers
low	lecture, videos, demonstrations

Figure 3.11 Bloom's analysis of selected instructional strategies.

An instructor teaching a class of mostly passive learners and/or extrinsically motivated learners (introductory courses) must begin with low-level instructional strategies and progress upwards. Very likely, the instructor will primarily use the lowest two levels. An instructor teaching advanced learners and/or learners who have similar interests (senior undergraduate and graduate courses) will be able to use higher-level instructional strategies.

Most introductory science courses have laboratory components, and students are often confused and/or frustrated because they do not see the connection between laboratory and classroom instruction. This is consistent with educational psychology because hands-on activities (laboratory experiments) are a high-level instructional strategy and novice students are uncomfortable with so much individual involvement. Since laboratory experiments are important for other pedagogical reasons, students would be more comfortable in the laboratory if the experiments relate to real-world phenomena. Laboratory experiments have increasing pedagogically importance in advanced courses, where learners will be more able to connect classroom and laboratory learning to improve their overall learning.

As learners become more intrinsically motivated and self-directed, they may be assigned lower-level instructional activities as pre-class assignments, leaving more instructional time for higher-level learning activities. *Flipped instruction* and *guided inquiry* are instructional strategies that require learners to be beyond the passive learner stage (see next section).

Learner development

Divisions within sociology, psychology, and psychiatry focus on research, application, and educating people about learner development. This section focuses on the development of learners in an academic environment and is based on two models of learner development.* The terminology and focus have been adapted to be consistent with this chapter.

Learners progress from a simplistic, categorical view of the subject to a realization that both knowledge and values are involved in decision making. There are four stages of learner development.

Passive learners expect to receive all the information they are required to learn from the instructor. They believe that there are obvious solutions to all problems.† They expect to be taught how to determine the "correct" solution, and perceive instructors as having and disseminating the "correct" solutions. Knowledge is perceived as known and absolute.

Active learners participate in instructional activities at the direction of the instructor. They realize that there may be multiple perspectives from which to analyze a problem, but struggle with the idea of multiple "correct" solutions. They do not understand and are frustrated with instructors who wants a particular solution and justification for that solution. Knowledge is perceived to be contextual and subjective since it is colored by a person's beliefs.

Engaged learners go beyond the minimum assigned learning activities. They prepare for class, read additional material on the topic, and complete additional exercises for their personal interest and to better their understanding. They make connections between concepts learned in different courses. They no longer expect instructors to give them the solution. Knowledge is perceived as understanding constructed from the available information, with the recognition that different weighting of information may produce different solutions.

* *Perry's model*, proposed by William Perry in 1970, explains the intellectual and ethical development of learners as they learn new concepts. Perry's model links the cognitive (intellectual) and affective (ethical, emotional) domains of Bloom's taxonomy.

Reflective Judgment model, proposed by Patricia King in 1994, focuses on the learners perception of knowledge and how knowledge must be justified.

† The "problems" referred to here are conceptual problems where there is more than one reasonable solution. (Algorithmic problems have definitive solutions.)
- Are nuclear reactors a viable long-term option for society's energy needs?
- What is the "proper" way to prepare microscope slides?

Self-directed learners independently identify and investigate concepts of personal interest. Their primary desire is to increase their knowledge. They are able to develop understanding and a solution after independently considering the available information. They are willing to defend their solution, debate the merits of different solutions, and possibly change their solution based on new information. Instructors are perceived as a source of expertise and as peers. Knowledge is perceived as the result of focused and critical analysis of the available information, and the applicability of that knowledge in other contexts.

A teacher is one who makes himself progressively unnecessary.

Thomas Carruthers

When learning a new subject, every learner starts as a passive learner. At each stage, learners progress from being *marginal*, to being *adept*, to being *impeded* by the stages' limitations. Being impeded facilitates/forces learners to transition to the next stage. The progression through the stages is irregular and generally difficult as more responsibility for learning is placed on the learner at every stage. A person's interest, effort, and their willingness to learn determines where they end. The adept self-directed learner is the pinnacle of intellectual development because the learner has the intellect to independently investigate and understand a concept, the ethical development to weigh the consequences of a decision, the willingness to make and defend a decision, and the openness to consider alternatives.

For example, most of the public are passive learners when considering science. They believe what they are told: that there is a single correct solution to scientific problems, and they are confused by conflicting arguments presented by scientists, industry, government, etc. Most learners enter university at either at either the passive or active learner stage, depending on the subject. Learners typically leave undergraduate university at the engaged learner stage in their major and minor, and at the active learner stage in other courses they have taken. Graduate students are expected to be self-directed learners in their thesis field when they complete their studies.

Consider the following activities:

- purchasing a vehicle
- listening to a politician
- having to go to court

If these are not activities you do regularly, they make you uncomfortable. The people familiar with these events exude confidence — salesmen, politicians, police, lawyers — and you find yourself trusting them. But very often, these people are *not* acting in your best interests. The more times you experience them, the more you see through the façade. This is one reason your parents are more cynical about politicians than you.

Instructors should teach in a way that presents an understanding at the given level and that can be built upon in future classes. Only once you have taken the future courses can you assess the quality of instruction of your previous courses.

The progression of *understanding*

Complementing the progression of the learner from passive to self-directed is a progression in understanding.

What is meant by *understanding* a concept?

- Being able to restate the concept? (alphabet, multiplication tables)
- Being able to apply it? (communication, algebra)
- Being able to develop it? (novels, poetry, calculus, derivations)

Understanding increases as a learner progresses through these stages. Figure 3.12 presents a progression of understanding.

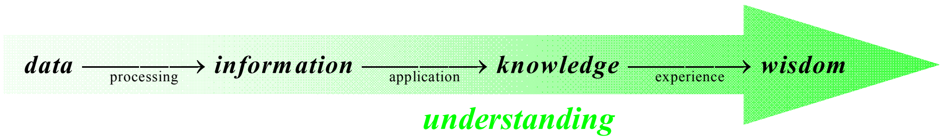


Figure 3.12 The building of understanding.

Where

- *data* is a collection of facts
- *information* is obtained by processing the data to identify trends, structure, and relationships in the data
- *knowledge* is obtained by applying the data and information to related and new systems
- *wisdom* is obtained with experience and continued knowledge acquisition

Progression to knowledge and wisdom requires a learner to be at the engaged or self-directed level and requires they apply high-levels of Bloom's taxonomy (Figures 3.9 and 3.10) to their learning.

Optimizing learning

The learner — no one else — determines how much learning occurs.

Figure 3.2 lists two types of instructional activities: *passive* and *active*. These correlate with the *passive* and *active* stages of learner development presented above. The final two stages — *engaged* and *self-directed* — are stages intrinsic to the learner. Only the learner can decide if they progress to and through these stages. Instructors can create environments conducive to learning and present information using optimal instructional strategies, but if the learner is not interested, no learning occurs and the learner does not progress. Indeed, the more ownership a learner takes in learning, the more they will learn and be prepared to learn in their future courses and careers.

Three types of learning are commonly observed.

Surface learning occurs when a learner focuses on memorizing new information, rather than linking it to their existing knowledge. This often occurs when the learner is not interested in a subject and endeavors to complete the minimum requirements in the course. The information is easily forgotten because there are few links to existing knowledge. For example, students who take notes verbatim and cram for exams are surface learning. Outside of academia, surface learning is used by people conducting one-time tasks, such as following repair or assembly instructions.

Deep learning occurs when a learner evaluates new information, endeavors to understand it, and links it to their existing knowledge. This occurs when the learner is interested and engaged in a subject, believes the information to be pertinent and valuable, and is interested in understanding the overall connectivity of information. For example, students who paraphrase or summarize notes are starting the deep learning process. Deep learning is mentally exhausting and requires a focused commitment to learning, but deep learning provides a person with knowledge they can use in their future careers.

Strategic learning occurs when a learner selects which information to deep learn and which to surface learn. For students taking courses, this is a risky strategy as the instructor controls the course emphasis. Learners, by definition, do not fully understand the intricacies of a subject and therefore are ill-prepared to decide what information is relevant. Successful strategic learning requires a large knowledge base from which to identify the important advanced concepts. Strategic learning may be successful for self-directed learners who are able to chart their learning objectives. Outside of academia, strategic learning occurs regularly. People with a special interest will learn information to satisfy that interest. The interest could be about something they heard, warranty or insurance information, criminal proceedings, etc. People expanding their work-related knowledge will strategically learn information.

Surface learning typically occurs when a learner is extrinsically motivated and a passive learner. Deep learning and strategic learning occur when a learner is intrinsically motivated and at the active, engaged, or self-directed stage.

> All learning starts as surface learning. For example, learning multiplication tables and the amino acids. Surface learning transforms into deep learning when the learner looks for patterns and insights into how information is connected and applied. Advanced learners combine these activities, so move directly to deep-learning.
> For example: linking the multiplication tables to counting-by-numbers and to formulae in science courses; and linking amino acid functional groups to hydrophobic and hydrophilic regions, and to the secondary and tertiary structure of proteins.

Strategies to optimize deep learning are presented throughout this chapter and are summarized below.

- identify and link concepts to existing knowledge
- build intrinsic motivation
- participate in active instructional exercises
- prepare and monitor your learning using self-regulated learning
- study with others; teach others
- practice recalling information
- renew and refocus your efforts when learning becomes difficult
- determine your preferred learning stages on Kolb's model, and work to improve the stages where you are weak

Figure 3.14 lists numerous learning strategies to enhance learning. Other resources provide details on how to implement these strategies.

In addition to *learning* information, you must also learn to *recall* information so that you can recall it when required: on exams, in future courses, in interviews, and in careers. The use of cue cards forces you to recall information randomly. At a higher level, teaching (formal and informal) requires you to recall information, formulate a coherent response, and present that information clearly and concisely.

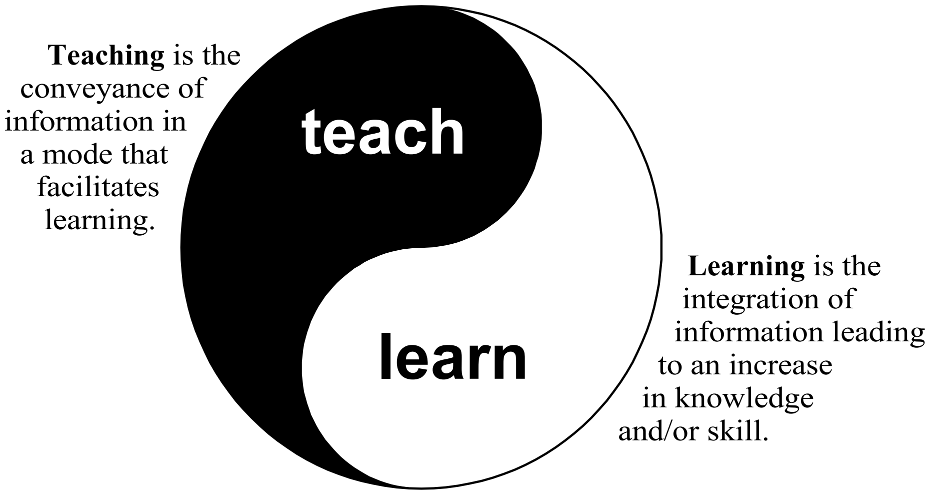


Figure 3.13 The complementary relationship between teaching and learning.

In the context of *Communicating Science*, knowing how people learn allows us to prepare documents and presentations that convey information in a manner conducive to learning.

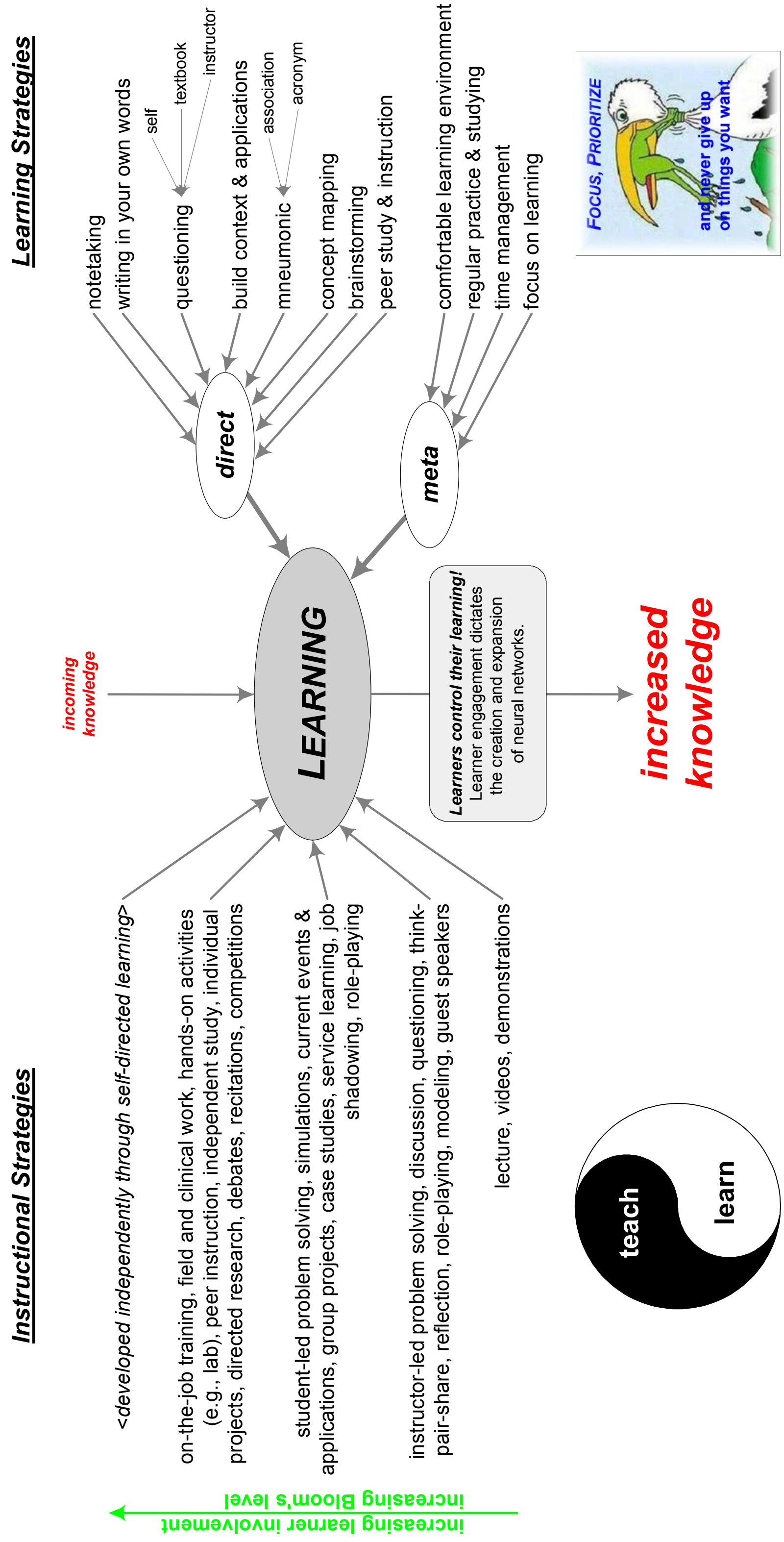


Figure 3.14 Instructional strategies and learning strategies effect on learning.

Additional learning considerations

Psychological and pedagogical research continues to identify factors that enhance and impede learning. Below are some recent findings.*

Multitasking. The brain functions optimally when focused on a single task. The brain is poor at multitasking when the same region of the brain is required for both tasks. For example, reading a textbook and watching television both require the vision and language procession regions of the brain. Using a laptop in class reduces learning by over 20 %. Listening to music *with* lyrics also degrades learning. However, listening to music *without* lyrics stimulates the brain and improves learning.

Source: Hembrooke H, Gay G. The laptop and the lecture: The effects of multitasking in learning environments. Journal of Computing in Higher Education. 2003;15(1):46–64.

Taking notes. Students who handwrite notes take more concise notes and deep-learn the material better than students who take notes on a computer. Additionally, students who handwrite notes do better on assessments. One survey found an average increase of 18 % for students who handwrite notes.

Source: Mueller PA, Oppenheimer DM. The Pen Is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking. Psychological Science 2014;25(6):1159–1168.

Practice makes permanent. A person's skill correlates with the amount of practice they do. Willingham argues there is no such thing as a prodigy, just people with a faster rate of skill development; prodigies too improve with practice. Importantly, learning incorrect information or practicing an technique improperly will embed that incorrect knowledge, making it exceedingly difficult to correct.

Source: Willingham DT. Practice Makes Perfect — but Only If You Practice Beyond the Point of Perfection. Ask the Cognitive Scientist. American Educator [internet] Spring 2004 [retrieved 08 August 2015]. Available from http://www.aft.org/periodical/american-educator/spring-2004/ask-cognitive-scientist

Condensed studying and instruction. Cramming for exams is an all-to-common strategy of students. In addition, a new instructional model involves students taking one course at a time, with each course taking around three weeks. (Traditional instruction involves students taking three to five courses at a time over 12 to 16 weeks.) New is not always better. Both cramming and condensed instruction result in reduced learning. Willingham shows that, when the students studied for the same amount of time, studying distributed over days resulted in more than twice the learning as cramming. Additionally, a students' ability to learn

* Only one or two representative citations are provided for each point. These articles may link to earlier articles with similar findings.

decreases substantially after approximately 60 minutes of instruction. Before being able to learn more, a student must take time to process the information they have into knowledge. That is, cramming and long classes are poorer learning strategies.

Taking multiple courses also allows the person to more broadly expand their neural network, with links forming across all of their courses.

Source: Willingham DT. Allocating Student Study Time: "Massed" versus "Distributed" Practice. Ask the Cognitive Scientist. American Educator [internet] Summer 2002 [retrieved 28 February 2016]. Available from http://www.aft.org/periodical/american-educator/summer-2002/ask-cognitive-scientist

Source: Brown PC, Roediger HL III, McDaniel MA. Make It Stick: The Science of Successful Learning. Belknap Press 2014.

Digital amnesia. Increased use of technology is resulting in people memorizing less information. Information is stored on electronic devices and looked up online. The reduced use of the storage and recall regions of the brain results in increased difficulty memorizing information, recalling information, and an overall decreased cognitive ability because the information must occupy the limited space of the working memory.

Source: Kaspersky Lab. The Rise and Impact of Digital Amnesia [internet] [retrieved 08 October 2015]. Available from https://blog.kaspersky.com/files/2015/06/005-Kaspersky-Digital-Amnesia-19.6.15.pdf

Optimizing instruction

Bloom's taxonomy classifies the *assessment* and *instruction*.
The learner development models classify the *learner*.

Effective instruction — instruction that facilitates the most knowledge in the learner — requires that both Bloom's taxonomy and the learner level be considered when deciding on instructional strategies and assessments.

Figure 3.15 shows that an assessment will have an inherent difficulty based on the level of learner development. For example, passive learners are comfortable with questions low on Bloom's scale and with instructor-led instruction. They find mid-level questions and guided instructional strategies challenging, and are unable to comprehend how to solve high-level questions. Passive learners are unable to effectively work on their own. Conversely, self-directed learners prefer questions that are at the mid and high-levels of Bloom's taxonomy because of the challenge they offer. Self-directed learners prefer learning independently and with peers in a collaborative environment.

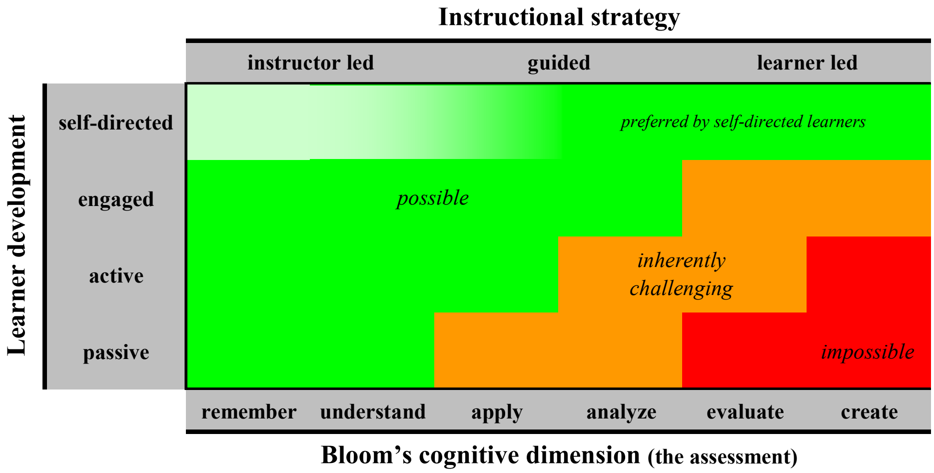


Figure 3.15 The inherent challenge of instructional strategies and assessments for learners at different levels of development.

Instructors should use instructional strategies from Figure 3.11 to create an active and engaging instructional environment. The selection should correlate to the *possible* and *inherently challenging* categories for the learner group. Figure 3.16 presents the progression of a learner's preference of instructional strategies as they develop academically. For instructors, it is important to challenge learners to facilitate their transition to the next level.

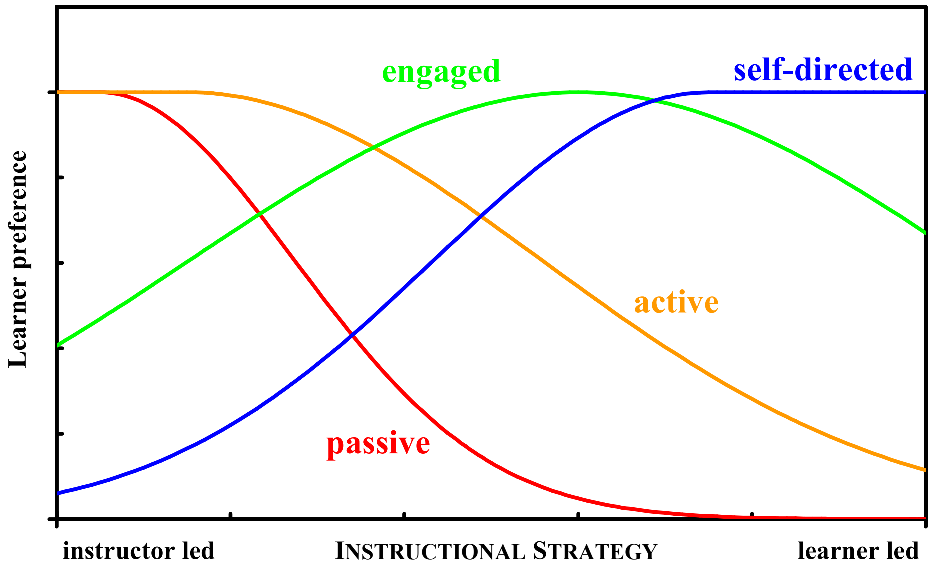


Figure 3.16 The progression of a learner's instructional preferences as they progress from a passive learner to a self-directed learner.

Typical instruction patterns

Instructors typically use instructional strategies that mirror their preferred learning style(s): they teach the way they learn. Students find learning easier when

- the instructor and student have similar learning styles (see Figure 3.6)
- the information being taught overlaps with the student's existing knowledge
- the student is interested in the information
- the instructor uses instructional strategies consistent with the learner's level

When any of the above are not present, learning is more difficult.* The student can still learn, but will feel somewhat frustrated. These are excellent opportunities for students to develop other learning styles. For instructors, teaching in an alternate style improves their ability to teach and learn in that style.

A significant problem occurs when a person learns incorrect information. The more layers of information built on incorrect information — the more neural networks that link to the incorrect information — the harder it is to correct the erroneous information. From an educational perspective, in order to achieve the greatest understanding, students must be taught truthful information in a manner that allows future learning to build upon that information. For example, some high school chemistry instructors teach that there are "seven different types of chemistry problems" and then teach ways of identifying the type of problem and their solutions. While this strategy may work with the simple problems students face in high school, it introduces a misconception that chemistry is strictly algorithmic, which limits the students' ability to apply what they learned in high school in their post-secondary chemistry courses and in the real world. Students who need chemistry in their future studies and/or future careers will discover that chemistry problems are varied and complex. They must unlearn the strategy taught in high school and learn a more generalized problem-solving strategy. It would be pedagogically better to teach general problem-solving skills that students can employ in all their classes, from chemistry to home economics to auto mechanics.

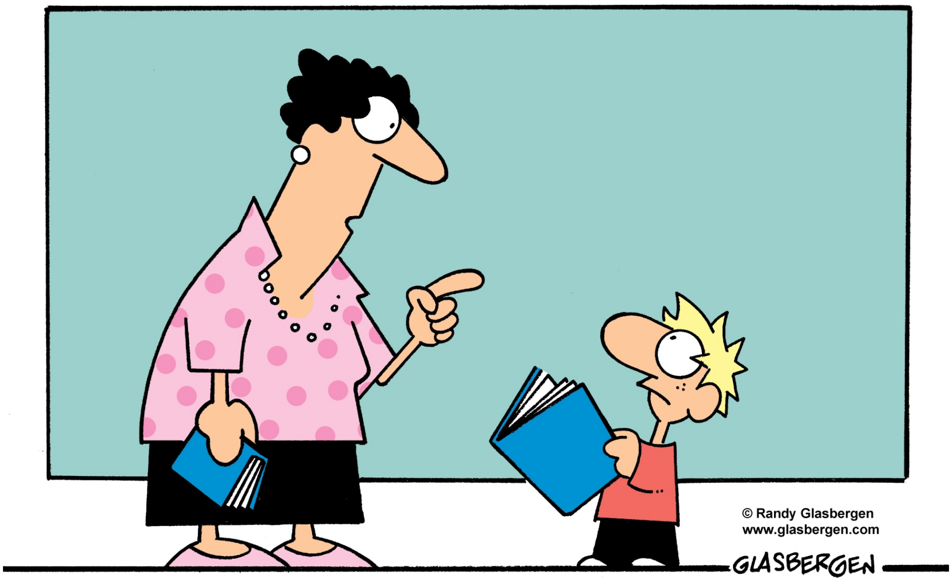
* This is why one person may struggle with learning from a particular instructor, while other students, with different preferred learning styles, learn well from that instructor.

3.4 Reading for understanding

Reading for pleasure is simple and enjoyable. Consider a novel, you read from the first page to the last, usually at a steady pace. After you have finished the novel, you are able to explain the overall story, but you do not recall many of the specific details. When reading for pleasure, you retain an average of 10 % of the details, as illustrated in Figure 3.2.

Reading for understanding requires a different approach and different mindset to optimize learning. This section focuses on reading academic works (textbooks, scholarly articles, etc.), but can also be applied to literary works (novels, plays, etc.) used in academic courses.

Academic works do not all have the same purpose. Textbooks are designed to present information to persons learning the material. Scholarly articles are designed to present information to other experts. The strategy to optimize learning from each differs slightly.



"It's called 'reading'. It's how people install new software into their brains".

This section provides general strategies to read for understanding. As you apply these strategies, you will develop your own style that best suits your learning style.

Activate your brain: talk to yourself and question yourself

Talking to yourself when reading makes the process active. Reading is a passive process, activating only the visual and memory regions of the brain. Talking activates the motor region, and listening activates the auditory region. Reading aloud increases brain activity as there are more inputs of the same information, which builds and reinforces diverse neural connections, improving learning.

As you read the text aloud, also ask yourself
- How does this explain or link to <another section or concept>?
- Can I relate this to things I already know?
- How might this be expanded later in the chapter/book/article?
- Where and how can I apply this now? in my career?

Strategies for optimized learning while reading a textbook

1. Establish a learning mindset

Establishing a learning mindset involves willing yourself into a psychological state where you want to learn the material. You are getting psyched! Learning improves when you perceive a subject to be interesting and relevant; when your mind is not distracted by personal problems; and when you are rested, clean, sated, and comfortable.

> *The mind is not a vessel to be filled, but a fire to be ignited.* — Plutarch

Strategies to establish a learning mindset include
- telling yourself that this material is interesting and important
- linking the material to your existing knowledge and interests
- explicitly identifying valuable and interesting components
- set milestones for learning, and a reward for each milestone

The long-term reward, of course, is doing well in the course, but short-term rewards provide the impetus to complete the immediate task: reading. The short-term rewards also introduce breaks into your study schedule. With the successful achievement of a milestone — and you know if it was successful or not — the 'reward' region of the brain releases endorphins that creates a positive, euphoric feeling in the body. Stimulating this region also encourages the body to continue to the next milestone, for the next reward. ☺

Ideally, set the milestones to coincide with the breaks in point 4, below.

2. Preview the chapter

In a novel, the last few chapters tie together all the threads in the book. The same occurs in each textbook chapter: the key concepts are near the end of each chapter. To optimize learning, it is important to know these key concepts before reading the text — this primes the mind to want to know how and why these key concepts were developed. Then as you read the text, you see how the material builds into the key concepts.

Indeed, academic works are structured to present the key concepts early. In textbooks, the key concepts are listed at the beginning and/or end of each chapter, in the *Overview* and *Summary*, respectively.

Previewing involves skimming most of the chapter, but reading certain sections. Specifically,

1. *read* the *Overview* and/or *Summary* to identify the key concepts
2. *skim* the text, but *read* the following:
    - headings and subheadings (important concepts, and links between them)
    - sentences with emphasized words (important or defined terms)
    - figures and tables, and their captions
    - the final section(s) in the chapter (develops many of the key concepts)

Figures and tables are often overlooked, but should be read thoroughly. They provide information in an alternate form, which is valuable for learning.

During the preview, identify links between the new information, your existing knowledge, and your interests.

3. Actively read the chapter

Knowing the key concepts, read the chapter to make and reinforce the connections between these concepts. Read aloud increases the sensory inputs of the same information, which improves learning. Also verbally express your commentary and questions on the material.* Consult other resources (dictionaries, textbooks, and colleagues) as required to understand the material.

After reading the chapter, go through each section and underline or highlight the major concepts in the section, how they link together, and how they link to concepts in other sections.

Finally, focusing on the information you underlined or highlighted, summarize this information in your own words. You are actually writing your own notes on the material.

* This may sound foolish, but it works for the reasons given on page 148.

If you find yourself making connections to things in your everyday life, and/or to things you are learning in other courses, great! This expands and reinforces the neural network in your brain.

Note: if you are applying this learning strategy to a short story or novel, you want to read the entire novel in step 2 and each chapter in step 3.

4. Take regular breaks

Take a break after every chapter and every hour, whichever comes first. Breaks give your mind time to process and connect the new information to your existing knowledge and connect the new concepts to each other.

Since you have been sedentary, get active: run, swim, cycle, lift weights, do yoga, martial arts, etc. Give yourself up to 30 minutes of physical activity for every hour of homework. Avoid watching TV or playing video games. Physical activity improves your state of mind and your health, which improves learning.

If you discover that you just spent hours reading, feel like you have learned a lot, and still feel energized, welcome to *the zone*.* Being *zoned in* is a psychological state of consciousness where you are completely immersed on a task. Learning is enjoyable and effortless, and is becoming intrinsic (see page 122). The more frequently you zone in to learning, the more enjoyable the learning becomes, the easier it becomes to zone in, and the better you learn the material. ☺

5. Review the material

Read the notes you took. Ensure they are a clear, concise, coherent, and precise summary of the key concepts and links between them. Add connections to related material in other chapters. These are your study notes, and you should not need to review the textbook unless you wish to review a figure or table, or have a question about something in your notes. When you review these notes, you build and reinforce in your mind the key concepts and connections between them, effectively rebuilding the chapter from your notes.†

* You have likely been zoned in to other activities and lost track of time and everything else occurring around you. People commonly zone in when reading a novel, playing sports, playing video games, watching TV, spending time with a significant other, etc. Some of these activities are beneficial, others simply waste time.

† People with in-depth knowledge of the subject — your instructors — can usually read the *Overview* or *Summary* and remind themselves of the key concepts and connections. As you get more familiar with the material, you may find that you can produce an even more concise summary by rewriting your notes.

If chapters build on each other, review your notes on the previous chapter before reading the current chapter so that the information is fresh in your mind and you can build connections across chapters.

Review all your notes weekly to reinforce the developing neural network and to develop links to the new material you are learning. Set up study groups where you discuss and share material, and challenge each other with questions. If you can dynamically recall and formulate answers to random questions on the material, you know it well.

> *To teach is to learn twice over.* — Joseph Joubert

Strategies for optimized learning while reading a scholarly article*

1. Establish a learning mindset

<same as reading a textbook>

2. Preview the scholarly article

Like textbooks, scholarly articles are also structured to present the key concepts early. In scholarly articles, the abstract presents this information.

Research follows the scientific method, and scholarly articles often follow the scientific method in presenting the research.

Previewing involves skimming the article and identifying the components of the scientific method.† Specifically, identify the

- *observation* that led to the research (in the abstract or introduction)
- *hypothesis* (the word "hypothesis" is not commonly used; look for phrases like, "This research shows …" or "We discovered that …".)
- *experimental method*
- *experimental results* (may be answered in figures and tables)
- *conclusions*

It is likely that you are interested in only one or a few aspects of the research. The *Introduction*, *Discussion*, and *Conclusion* sections explain the current understanding of the scientific field. The *Method* and *Results* section is valuable to people wishing to conduct similar studies/

* Adapted from Robertson K. A journal club workshop that teaches undergraduates a systematic method for reading, interpreting, and presenting primary literature. Journal of College Science Teaching. 2012;41(6):25–31.

† The scientific method is presented on page 4.3.

experiments. However, it is important to read the entire article to obtain a general understanding of the entire academic work.

3. Actively read the scholarly article

The Preview provides you with the key information the article endeavors to convey. Now read the article to make and reinforce the connections between this information. Questions you should answer include:

- Why is the hypothesis interesting and important to investigate?
- Why is the experimental method valid for this research?
- How does the experiment work? What was controlled? What was measured?
- What are the limitations of the experimental method?
- What information is conveyed in the figures?
- How was the data analyzed?
- Do the results support the hypothesis? Is the analysis reasonable and statistically valid?
- What new information does this research add to the scientific field?
- How could the experiment be improved?
- What further experiments could be conducted?
- <any specific questions you have about the research>

Read the article aloud and verbally express your commentary and questions on the article. Underline or highlight information that answers the questions. Focusing on the information you underlined or highlighted, prepare a summary of the article in your own words. Section 5.5 explains how to prepare an article summary.

4. Take regular breaks

<similar to reading a textbook>

5. Review the material

< similar to reading a textbook>

To understand why this process works, consider watching a movie. The first time you watch it, there is action that may not make sense. However as the movie ends, the plots and subplots draw together and you understand the actions and connections between them. You make more connections as you chat with your friends after the movie. When you watch the movie again, you can better follow the plot and action because you know what is going to happen. You notice additional actions and better understand the movie.

When reading a scholarly article or book, the goal is obtaining a deep understanding of the material. Skimming the material gives you a basic understanding and you learn the key concepts. The second reading reinforces the development of the key concepts and deepens understanding of all the material.

Concept maps and flowcharts

In addition to writing notes in paragraph form, you may augment your notes with *concept maps* and/or *flowcharts*.

- A ***concept map*** is a graphical representation of the concepts and connections between them.
- A ***flowchart*** is a graphical representation of a workflow or process.

By themselves, they do not contain sufficient detail for in-depth learning, but they do provide an overview of the connectivity between concepts and do break up the text, which is valuable for learning.

A sample concept map is presented in Figure 3.1, and there are several flowcharts in Chapter 5.

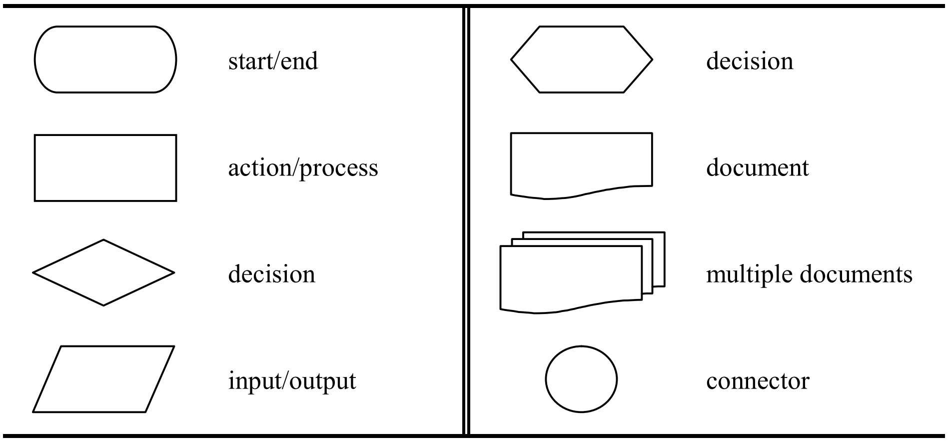


Figure 3.17 Common flowchart symbols.

3.5 Effective learning and studying strategies

Each of these strategies will improve your understanding of the material. The more strategies you apply, the greater your understanding.

1. **Preview the text before class.**

   Don't expect to understand it, just read it. This acquaints you with the information so that the classroom is where you see the material for the second time. You *will* find yourself saying, "Oh, so that's what the textbook means!"

2. **When reviewing, don't just read, write and talk!**

   Writing and talking are forms of active learning.
   Taking notes, rewriting your notes, and completing assignments use motor skills that strengthen and expand neural networks. Rewriting your notes (weekly, before exams, and at the end of term) forces you to critically review the information, follow the 'train-of-thought' of the instructor, and repeat it in your own words. Importantly, you end up with a smaller but complete set of notes from which to study!
   Prepare cue cards or a 'super-summary' of your notes. These contain only the major concepts and key points. When studying, read a key point and then fill in the details in your mind.
   Talking forces you to dynamically formulate your knowledge into coherent statements, again using and expanding the neural networks.
   Working in peer groups (two to six people) is an excellent way to pool and share knowledge. Students often explain concepts in a way that peers can relate to and teaching others is an excellent way to learn.

3. **Study in intervals, and get exercise.**

   Several factors that improve learning include studying for 60 to 90 minute periods, exercising between study periods, and studying at regular intervals.
   After 60 to 90 minutes, the brain has absorbed as much information as it can reasonably process. Taking a 15 to 45 minute break after studying allows the brain to process the information. During the break, get some exercise. Exercise stimulates blood flow and brain activity, which facilitates subconscious processing of the information into knowledge. (Video games and the internet are not 'exercise'. Get active: for a walk, run, bike ride, swim, etc. Play basketball or tennis with your study partner. You do have a study partner, don't you?)

4. **Don't memorize, build associations and learn the big picture.**

   Memorization only works for the questions at the lowest level of Bloom's Taxonomy. As you progress with your education, there will be too much information to memorize and memorization will be insufficient as courses expect you integrate diverse concepts together to analyze, evaluate, and create knowledge.

   To better learn material, build links between what you are learning and your existing knowledge. Endeavor to understand how the information integrates into and expands your overall understanding of the subject. Identify applications of the information both within the subject and in everyday use.

5. **Don't pull 'all-nighters'.**

   Your ability to learn when fatigued is very low. Your mind's ability to recall information and dynamically formulate answers is faster if you get a good night's sleep, not live off caffeine, etc.

6. **Don't study right up to the exam.**

   Take at least a four-hour break before the exam. Your mind can better consolidate what you have learned if you aren't cramming more in. Get active: go for a walk, to the gym, etc. Exercise will refresh your mind and you will be able to recall information faster.

Exam "cheat sheets"

Some instructors allow students to bring a "cheat sheet" — a piece of paper (or index card) with whatever information they want on it — it to the exam. A key caveat is that each student is required to prepare their own cheat sheet by hand. Electronically prepared pages and photocopied cheat sheets are forbidden. This is a great active instructional strategy. Each time you review and condense your notes, you improve your understanding of the material.

Most students discover that they have little need for their cheat sheet during the exam because they have learned the material so well. Even if you can't bring the cheat sheet to the exam, it is an excellent study strategy and provides you with a condensed set of notes to study from.

3.6 A process to maximize exam grades

1. **Read the exam start to finish.**

   This should take no more than a few minutes but will give you an overview of the entire exam. Your mind will unconsciously begin processing all the questions. Some instructors even give hints/answers to some questions in other questions.

   How many times have you been stumped on a question during the exam and then, while walking away, had a revelation on how to answer it. You weren't thinking about it, were you? Now consider if your mind had been unconsciously processing that question for a while longer (like from the start of the exam).

2. **Go through the exam and answer questions you know 'by heart'.**

   Your train-of-thought should be, "One: I know how to do this ... <answer>. Two: not a clue. Three: hmmm, not really sure. Four: oh yeah, that's how four is done ...<answer>. Five: like this ... <answer>. Six: …"

   Rereading the questions will keep your mind working on them. When the revelation strikes: "Oh yeah, that's how question three is done!", go back and complete three while it is still fresh in your mind. If you are stuck on a question, move on to the next one.

3. **Write something for questions you haven't tried yet.**

   Some questions will be complex, and there may be more than one path to the correct answer. Writing may spark an idea. Try rewriting the question in your own words and jotting down ideas. Don't be afraid to write something that may be wrong. If nothing else, putting something on paper may give you part marks. ☺

4. **Reread each question and your answer.**

   If you begin to second-guess yourself, leave the first answer! Studies have shown that the first answer is more often correct. Only change an answer if there is an obvious mistake, such as you misinterpreted the question. For mathematical questions, consider:

   - Is the answer of reasonable magnitude? Is it dimensionally correct (unit analysis)?
   - Redo the calculations to ensure you haven't made a simple mathematical error.

Additional resources …

... on constructivist learning

Wikipedia. Constructivism (philosophy of education) [internet]. Available from en.wikipedia.org/wiki/Constructivism_(philosophy_of_education)

Wikipedia. Constructivist teaching methods [internet]. Available from en.wikipedia .org/wiki/Constructivist_teaching_methods

... on self-determination theory

Self-Determination Theory [internet]. Available from www.selfdetermination theory.org

Wikipedia. Self-determination theory [internet]. Available from en.wikipedia.org/ wiki/Self-determination_theory

... on self-regulated learning

Wikipedia. Self-regulated learning [internet]. Available from en.wikipedia.org/wiki/ Self-regulated_learning

Zimmerman BJ. Becoming a self-regulated learner: An overview. Theory Into Practice, 2002;41:64–70.

Zumbrunn S, Tadlock J, Roberts ED. Encouraging Self-Regulated Learning in the Classroom: A Review of the Literature [internet] 2011. Available from www.self-regulation.ca/download/pdf_documents/Self%20Regulated%20Learning.pdf

... learning and the brain

Kolb D. Learning style inventory. Boston: McBer and Company; 1985.

Zull J. The art of changing the brain. Sterling (VA): Stylus Publishing; 2002.

Persons wishing to determine their preferred learning style(s) can find several learning styles assessments online.

... on Bloom’s taxonomy

Anderson LW, Krathwohl DR, editors. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Boston: Allyn and Bacon; 2001.

Clark D. Bloom’s Taxonomy of Learning Domains [internet]. Available from www.nwlink.com/~donclark/hrd/bloom.html

Krathwohl DR. A revision of Bloom's taxonomy: An overview. Theory Into Practice 2002;41(4):212–218.

… on learning models

Biggs J. Teaching for quality learning at university. Buckingham: Society for Research into Higher Education and Open University Press. 1999.

Finster DC. Developmental instruction: Part 1. Perry's model of intellectual development. Journal of Chemical Education. 1989;66(8),659.

Finster DC. Developmental instruction: Part II. Application of the Perry model to general chemistry. Journal of Chemical Education. 1991;68(9),752.

King PM. Reflective Judgment [internet]. Available from www.umich.edu/~refjudg/

King PM. William Perry's theory of intellectual and ethical development. New Directions for Student Services 1978(4):35–51.

Perry's Intellectual Scheme [internet]. Available from www.lib.jmu.edu/documents/academicrigor/Pedagogy/DOC002.PDF

Rapaport WJ. William Perry's Scheme of Intellectual and Ethical Development [internet]. 26 September 2013. Available from www.cse.buffalo.edu/~rapaport/perry.positions.html

Wikipedia. DKIW Pyramid [internet]. Available from en.wikipedia.org/wiki/DIKW_Pyramid