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Instructional Design Principles

Instructional design (ID) principles are rules that govern the methods and materials prescribed to facilitate human learning. Such principles may be used by educators and instructional designers to ground the design of training, education, and professional development on research and theory related to human learning, and to direct evidence-based practice. Instructional principles may also be used by organizations to set design standards, specify design requirements, and establish guidelines for large scale instructional design initiatives. Published ID principles are compiled to help educators and designers compare and contrast belief systems and to make informed design decisions.

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Behavioral Design Principles
(Reeves & Reeves, 2015)

In the early to mid-1900's, scientists recognized that learning occurred inside the brain, but since they could neither see nor measure such internal processes, they relied on observations of overt behaviors to explain and predict human learning. Behaviorists' viewed learning as a change in behavior that could be explained by external factors and behavioral conditioning. Interest in behaviorism peaked between 1955 to 1965 with the development of analog teaching machines and programmed instruction (Lumsdaine & Glaser, 1960, as cited in Reeves & Reeves, 2015). Behaviorists argued that operant conditioning and other principles related to reinforcement could be used to teach students in varied educational settings (Reiser 2001).

Instructional design principles derived from behaviorist learning theory include:

- Active learner participation in responding to instructional stimuli is much more effective than passive observation of instruction.
- Behaviors that are rewarded are more likely to be repeated than behaviors that are ignored.
- Immediate reinforcement is more effective in most cases than delayed reinforcement.
- Intermittent reinforcement is more effective than constant reinforcement. – Extinction, i.e., withholding reinforcement of a behavior or ignoring it can result in the decrease of that behavior.
- Extensivepracticewithpositivereinforcementisapowerfulmethodfordeveloping fine motor skills such as playing a piano or injecting a vaccine.
- Information should be presented in small amounts so that responses to questions about the information can be reinforced frequently.

(Reeves & Reeves, 2015, p. 468-469)

Cognitive Information Processing Design Principle
(Reeves & Reeves, 2015)

By the mid to late 1900's, psychologists reasoned that we could no longer ignore what was happening in brain to explain complex forms of learning, and began to formulate cognitive theories of human learning. In addition to observations, cognitive theories explain learning based on paper and pencil tests that measure internal psychological constructs, such as intrinsic and extrinsic motivation (Schunk, Meece, & Pintrich, 2013), Cognitive information processing (CIP) theories relate human learning to functions of computers in which different types of memory, such short-term, long-term and working memory (Anderson, 2000). CIP theories are especially popular among cognitive and computer scientists involved in developing intelligent tutoring systems and other applications of artificial intelligence to promote learning (VanLehn, 2011, as cited in Reeves & Reeves, 2015).

Instructional design principles derived from cognitive information processing learning theory include:

- Working (short-term) memory has inherent limitations that place a cognitive load on learning processes that must be carefully managed during instruction. Instruction should be designed to minimize the cognitive load of extraneous factors (e.g., the user interface of a computer program) and maximize the cognitive capacity to process information needed for learning.

- There are two separate channels that humans use for processing information during instruction, the auditory and visual, and thus, instruction should provide verbal and graphical information in ways that clearly guide the learners to identify and process relevant words and images.

- Learning occurs when humans identify, filter, select, link, organize, and integrate information under the guidance of a tutor, which may be human or computer-based.

- Content to be learned should be organized from simple to complex.

(Reeves & Reeves, 2015, p. 469-470)

Cognitive Theory of Multimedia Learning and 12 Principles of Multimedia Design
(Mayer, 2009)

Based on numerous experiments and Paivio's dual-coding theory, Baddeley's model of working memory, Wittrock's theory of generative learning, and Sweller's cognitive load theory, Mayer (2009) derived three basic assumptions about how humans process information. The summary of the three assumptions are quoted directly from https://ctl.wiley.com/principles-of-multimedia-learning/.

The Dual-Channel Assumption

According to Mayer (2009), the dual-channel assumption dictates that "humans possess separate channels for processing visual and auditory information" (p. 63). The first is the visual–pictorial channel, which processes images seen through the eyes (including words displayed on a screen). The other channel is the auditory–verbal channel, which processes spoken words.

The Limited-Capacity Assumption

The limited-capacity assumption suggests that humans have a hard limit on the amount of information they can process at any given moment. This is probably intuitive to anyone who's sat in a sports bar and tried to watch several games at the same time or tried to listen to the news while having a conversation. Although it's difficult to nail it down, Mayer suggests that most people can maintain maybe five to seven "chunks" of information in working memory at a given time (p. 67). He also indicates that individuals at the higher end of that range may have stronger metacognitive strategies, which allow them to manage their limited cognitive resources more efficiently.

The Active-Processing Assumption

The active-processing assumption asserts that humans don't learn by just passively absorbing information. Instead, they need to engage in active cognitive processes, namely identifying and selecting relevant material, organizing it into visual and/or verbal models, and integrating those new models with prior knowledge (p. 70). The cognitive theory of multimedia learning fundamentally argues against a "knowledge transmission" approach to learning in favor of a student-centered "knowledge construction" model. Students, he argues, are not "empty vessels" waiting to be filled up with information but must instead work to synthesize words and pictures into meaningful information that is stored in long-term memory.

The three assumptions serve as the foundation of Mayer's (2001) cognitive theory of multimedia learning that postulates twelve principles for designing and organizing multimedia presentations, including:

1. **Coherence Principle** – People learn better when extraneous words, pictures and sounds are excluded rather than included.

2. **Signaling Principle** – People learn better when cues that highlight the organization of the essential material are added.

3. **Redundancy Principle** – People learn better from graphics and narration than from graphics, narration and on-screen text.

4. **Spatial Contiguity Principle** – People learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen.

5. **Temporal Contiguity Principle** – People learn better when corresponding words and pictures are presented simultaneously rather than successively.

6. **Segmenting Principle** – People learn better from a multimedia lesson is presented in user-paced segments rather than as a continuous unit.

7. **Pre-training Principle –** People learn better from a multimedia lesson when they know the names and characteristics of the main concepts.

8. **Modality Principle –** People learn better from graphics and narrations than from animation and on-screen text.

9. **Multimedia Principle –** People learn better from words and pictures than from words alone.

10. **Personalization Principle –** People learn better from multimedia lessons when words are in conversational style rather than formal style.

11. **Voice Principle –** People learn better when the narration in multimedia lessons is spoken in a friendly human voice rather than a machine voice.

12. **Image Principle –** People do not necessarily learn better from a multimedia lesson when the speaker's image is added to the screen.

Evidence-Based Micro Learning Strategies
(Smith and Ragan, 1999)

One of the fundamental principles of instructional design (ID) is that the design of instruction should be based on the desired learning outcome. To apply the principle, Smith and Ragan identified various micro-strategies that have been found to facilitate the achievement of specified learning outcomes based on a review of over 50 years of research on teaching and learning, as depicted in Table 1.

Table 1. Evidence-based learning strategies correlated to various learning outcomes

Learning Outcome	**Evidence-Based Micro Learning Strategies**
Verbal Information Declarative knowledge: Names, labels, facts or a collection of propositions.	Associational Techniques • *Mnemonics Devices* (e.g., "FACE" for "Every Good Boy Does Fine"). • *Metaphoric Devices* (e.g., "white cells attack infections like soldiers attack enemy"). • *Instructor or learner generated images* (e.g., pictures, graphs, tables). • *Rehearsal* (e.g., Drill & Practice). Organizational Techniques • *Clustering and chunking* into categories (e.g., periodic table). • *Expository and narrative structures (*e.g., chronologies, cause and effect relationships, problem solutions, comparisons and contrasts). • *Graphic and advanced organizers* (e.g., concept tree linking new to prior knowledge). Elaboration Techniques • *Write meaningful sentences* (e.g., sentences using elements of periodic table). • *Devise rule* (e.g., describe why elements are organized in rows and columns).
Concepts Objects, symbols or events grouped together on the basis of shared characteristics which can be referenced by a particular name or symbol.	• *Inquiry Approach* typically begins with a presentation of examples and non-examples of a concept (aka. exploratory or discovery learning). • *Expository Approach* begins with an explanation of a concept and its key attributes. • *Attribute Isolation* points out the critical attributes of a concept). • *Concept Trees* consist of hierarchical, graphic representations that illustrate the relationships between to subordinate and superordinate concepts. • *Analogies* compare two things, supplied by instructor or generated by learners. • *Mnemonics* facilitate learning when verbal information is important to concept learning or for helping learners remember the key attributes of a concept • *Imagery* - A mental image of concrete concepts, such as pictures, graphs, tables and maps presented by the instruction or generated by learners).
Rules Relational rules or principles and procedural rules or procedures.	Procedural Rules (Procedures) • Learn to *determine if the procedure is required*. • Learn to *list the steps in a procedure*. • Learn to *complete the steps in a procedure*. • Learn to *elaborate sequence*, starting with simple epitome of rule and elaborating to more complex versions of same rule. • Learn to *check appropriateness of completed procedure*. Relational Rules (Principles) • Ask learners to create their own *mnemonic device(s)* to support principle • Ask learners to create *images/diagrams* that illustrate relationships of concepts as presented in the principle • Practice *stating principle* (in own words). • Practice *recognizing situations* where principle is applicable. • Practice *applying principle* to predict, explain, or control for effects of one concept on another. • Practice *determining if principle was applied correctly*.

Problem Solving Combine learned principles, procedures, verbal information and cognitive strategies in a unique way within a domain to solve original problems. Includes both well-defined (or structured) problems and ill-defined (or structured) problems.	• *Presentation of the Problem* - Case studies, simulations, limiting the number of rules–principles and procedures–that must be used, presenting explicit representations of necessary rules as cues, providing solutions to parts of the problem, limiting the amount of extraneous information). • *Problem Space* - Review directions and identify relevant information about goal state; Delineate and analyze relationship between current and goal states; Discern patterns; Define what is known and unknown about the problem and determine what information must be acquired to solve the problem; Break down the problem into intermediate states or subgoals). • *Appropriate Principles* - Guided questions (generative approach) or direct statements (supplantive approach) on how to select and apply appropriate principles and procedures to move from the given state, through intermediate states, to the goal state. • *Practice* - Present multiple representations of the problem; Recommend techniques for limiting alternative approaches to problem resolution; Provide clues about the general form of the solution; Recommend search strategies for acquiring relevant information; Outline generic approaches for problem resolution such as hypothesis testing and working backwards; Establish criteria for evaluating the appropriateness of alternative solutions.
Cognitive Strategies Internally organized skills used to regulate and monitor the utilization of concepts and rules. Includes cognitive domain (i.e., organizing, elaborating, rehearsing, and metacognitive strategies) and affective domain (support) strategies.	• *Discovery and Guided Discovery* help learners ascertain particular strategies through the application of questioning strategies. Guided discovery involves more direct instruction (such as a demonstration) than discovery. • *Observations* enable learners to witness a model demonstrating the use of the strategy by paired, cooperative learners, expert demonstration; and symbolic visual or textual representation by fictional character(s). • *Guided Participation* - Instructor works with learners to determine characteristics of learning task, identify strategies to facilitate the task, and determine effective methods for employing the strategy • *Direct Instruction* - Identify utility of the strategy; Provide overview of steps and their relation to overall strategy; Demonstrate or model the strategy; Illustrate examples and non-examples of strategy use; Practice application of the strategy across gradually more difficult situations; Provide corrective feedback; Encourage and guide transfer of strategy to separate but appropriate context). • *Dyadic instruction* is a goal-directed teaching method where students are randomly assigned into dyads and work together to solve inquiry-type problems. • *Self-instruction* is a self-management strategy that contributes to an individual's self-determination skills. It can help a consumer to self-manage existing skills as well as learn new skills. The goal of self-instruction is to support a person to independently complete a task.

Attitudes Choice behaviors that make certain classes of action more or less probable	• *Demonstrate* desired behaviors representative of target attitude by a respected role. • *Practice* desired behavior associated with the desired attitude is another powerful tool in attitude formation and change (e.g., role playing and group discussions). • *Provide reinforcement* for the desired behavior (a stimulus that increases the probability of the preceding behavior reoccurring. • *Communicate persuasive messages* from highly credible sources. • *Create dissonance* (persuading learner to perform an important behavior that is counter–dissonant–to the person own attitude, attitude change may result.
Psychomotor Skills Coordinated muscular movements that may be difficult to distinguish from intellectual skills	• *Massed versus Spaced Practice* - Massed practice engages learners in one or a few intensive periods of practice. Spaced practice exposes learners to short practice sessions distributed over time. • *Whole versus Parts Practice* - Whole practice is advisable if the task is simple, not meaningful in parts, made up of simultaneous performed parts and has highly dependent parts, and if the learner is able to remember long sequences, has long attention spans and is highly skilled. • *Progressive parts practice* - If learners may have difficulties putting the parts together into a meaningful and well executed whole. • *Backwards chaining* - Where learners are exposed to and practice the last step and work their way to the first step.

Universal Principles of Experiential Learning
(Lindsey & Berger, 2009)

Experiential approaches to teaching and learning are based on two central principles originally posited by Dewey in 1920's and 30's: (a) continuity (the idea that students learned from their experiences), and (b) interaction (the notion that students' experiences were derived from their interactions with the environment and other individuals) (Dewey, 1938, p. 25). Experiential learning is also grounded in the belief that children, adolescents and adults learn best when presented with relevant, meaningful and interesting goals, and foster skill development and the learning of facts, concepts, procedures, and principles in context of how they will be used.

The merits of experiential learning have resulted in a number of recent models, including, but not limited to those posited by Kolb (Kolb, 1984; Kolb & Fry, 1975), Schank, Berman and Macpherson (1999) and Clark (2004). With the plethora of interpretations, Lindsey and Berger (2009) synthesized published approaches, identifying four central tenets of experiential learning to guide research and practice (i.e., learning should be student-centered rather than teacher-directed, focus on real-world experiences, include a high degree of self-direction for decision-making, and consist of feedback regarding the decisions made by the student) and three universal and sequential principles of experiential learning.

Principle 1 - Frame the Experience. The first phase includes communicating the instructional objectives, assessment criteria, expected behaviors, and social structure (with peers, instructors and the environment beyond the class). Variable methods such as didactic instruction may also occur in this phase to provide the foundational knowledge required to successfully engage in and interpret the experience.

Principle 2 - Activate Experience. Activating prior as well as newly initiated experiences are necessary. There are multiple methods for activating experience ranging from laboratory practice to simulations. Key characteristics of activating experience include: (a) providing an authentic experience to facilitate transfer; (b) making decisions that have authentic outcomes; (c) problem orientation so learners clearly perceive and accept the relevance of the specific learning activities in relation to the larger talk problem; and (d) present optimal difficulty to challenge the student but not so difficult that the student does not have a reasonable expectation for success.

Principle 3 - Reflect on Experience. Experience must be analyzed to learn from it. Reflection should involve students answering the questions, "What happened?" "Why did it happen?" "What did I learn?" and "How would I apply this knowledge to future experiences?" Specific methods for stimulating reflection include: (a) teacher facilitation to help learners to identify their beliefs and working with them to master impediments to understanding; and (b) community building which is a part of framing the experience but should be pursued prior to reflecting. A significant element of community building is communicating the equality of the participants and their role in the active critique of others' experience.

Adult Learning Principles
(Knowles, 1970)

1. **Adults tend to be self-directed.** Adults want to participate in the planning and evaluation of their learning.
2. **Adults have rich reservoir of experience.** Adults prefer to build on prior learning and experience.
3. **Adults need to learn experientially.** Adult learn by doing; experiences form bases for knowledge construction.
4. **Adults have problem-solving orientation.** Adults are problem-centered rather than content-oriented
5. **Adults' motivation affected by need to know**. Adults most interested if learning has immediate relevance to job or personal life
6. **Adults motivated by internal/intrinsic factors.** Grades and other extrinsic rewards not as effective with adults.

Adult [Instructional] Design Principles:

1. **Control**. Adults need to be involved in the planning and evaluation of their instruction
2. **Prior Knowledge**. Instruction should stimulate prior knowledge and relate to prior experiences.
3. **Experiential**. Experience (including mistakes) provides the basis for learning activities
4. **Problem-based**. Adult learning is problem-centered rather than content-oriented
5. **Relevance**. Adults are most interested in learning about subjects that have immediate relevance to their job or personal life

Prior Knowledge & Experience (Briefcase):

1. Life experience (including life altering events that affect cognitive abilities)
2. Work experience (including development of thinking patterns based on this experience)
3. Positive/negative previous adult learning experiences
4. Performance affecters, including cognitive abilities
5. Time between learning interactions
6. Aging factors

Learner-Centered Psychological Principles
(APA, 1997)

Cognitive and Metacognitive Factors

1. ***Nature of the learning process*.** The learning of complex subject matter is most effective when it is an intentional process of constructing meaning from information and experience.

2. ***Goals of the learning process.*** The successful learner, over time and with support and instructional guidance, can create meaningful, coherent representations of knowledge.

3. ***Construction of knowledge***. The successful learner can link new information with existing knowledge in meaningful ways.

4. ***Strategic thinking.*** The successful learner can create and use a repertoire of thinking and reasoning strategies to achieve complex learning goals.

5. ***Thinking about thinking.*** Higher order strategies for selecting and monitoring mental operations facilitate creative and critical thinking.

6. ***Context of Learning.*** Learning is influenced by environmental factors, including culture, technology, and instructional practices.

7. *Motivational and Affective Factors*

8. ***Motivational and emotional influences on learning.*** What and how much is learned is influenced by the learner's motivation. Motivation to learn, in turn, is influenced by the individual's emotional states.

9. ***Intrinsic motivation to learn.*** The learner's creativity, higher order thinking, and natural curiosity all contribute to motivation to learn. Intrinsic motivation is stimulated by tasks of optimal novelty and difficulty, relevant to personal interests, and providing for personal choice and control.

10. ***Effects of motivation on effort.*** Acquisition of complex knowledge and skills requires extended learner effort and guided practice. Without the learner's motivation to learn, the willingness to exert this effort is unlikely without coercion.

11. Developmental and Social Factors

12. ***Developmental influences on learning.*** As individuals develop, there are different opportunities and constraints for learning. Learning is most effective when differential development within and across physical, intellectual, emotional, and social domains is taken into account.

13. ***Social influences on learning.*** Learning is influenced by social interactions, interpersonal relations, and communication with others.

14. Individual Differences

15. ***Individual differences in learning.*** Learners have different strategies, approaches, and capabilities for learning that are a function of prior experience and heredity.

16. ***Learning and diversity.*** Learning is most effective when differences in learners' linguistic, cultural, and social backgrounds are taken into account.

17. ***Standards and assessment.*** Setting appropriately high and challenging standards and assessing the learner as well as learning progress—including diagnostic, process, and outcome assessment—are integral parts of the learning process.

Cognitive Constructivist Teaching Practices and Principles
(Bonk & King, 2009)

1. ***Mind**:* The mind is in the head; hence, the learning should focus on active cognitive reorganization.

2. ***Raw Materials**:* Use raw or primary data sources, manipulatives, and interactive materials.

3. ***Student Autonomy**:* Ask students for personal theories and understandings before any instruction. Allow student thinking to drive lessons and alter instruction based on responses. Place thinking and learning responsibility in students' hands to foster ownership.

4. ***Meaningfulness and Personal Motivation**:* Make learning a personally relevant and meaningful endeavor. Relate learning to practical ideas and personal experiences. Adapt content based on student responses to capitalize on personal interests and motivation.

5. ***Conceptual Organization/Cognitive Framing**:* Organize information around concepts, problems, questions, themes, and interrelationships, while framing activities using thinking- related terminology (e.g., classify, summarize, predict).

6. ***Prior Knowledge and Misconceptions**:* Adapt the cognitive demands of instructional tasks to students' cognitive schemes, while building on prior knowledge. Design lessons to address students' previous misconceptions, for instance, by posing contradictions to original hypotheses and then inviting responses.

7. ***Questioning**:* Promote student inquiry and conjecture with open-ended questions. Also, encourage student question-asking behavior and peer questioning.

8. ***Individual Exploration and Generating Connections**:* Provide time for the selection of instructional materials and the discovery of information, ideas, and relationships. Also, includes encouraging students to generate knowledge connections, metaphors, personal insights, and build their own learning products.

9. ***Self-Regulated Learning**:* Foster opportunity for reflection on skills used to manage and control one's learning. Help students understand and become self-aware of all aspects of one's learning, from planning to learning performance evaluation. Given the focus on individual mental activity, the importance of cooperative learning or peer interaction is in the modeling of and support for new individual metacognitive skill.

10. ***Assessment**:* Focus of assessment is on individual cognitive development within predefined stages. Use of authentic portfolio and performance-based measures with higher order thinking skill evaluation criteria or scoring rubrics.

Social Constructivist Teaching Practices and Principles
(Bonk & King, 2009)

1. ***Mind****:* The mind is located in the social interaction setting and emerges from acculturation into an established community of practice.

2. ***Authentic Problems****:* Learning environments should reflect real-world complexities. Allow students to explore specializations and solve real-world problems as they develop clearer interests and deeper knowledge and skills.

3. ***Team Choice and Common Interest****:* Build not just on individual student prior knowledge, but on common interests and experiences. Make group learning activities relevant, meaningful, and both process and product oriented. Give students choice in learning activities. Foster student and group autonomy, initiative, leadership, and active learning.

4. ***Social Dialogue and Elaboration****:* Use activities with multiple solutions, novelty, uncertainty, and personal interest to promote student-student and student-teacher dialogue, idea sharing and articulation of views. Seek student elaboration on and justification of their responses with discussion, interactive questioning, and group presentations.

5. ***Group Processing and Reflection****:* Encourage team as well as individual reflection and group processing on experiences.

6. ***Teacher Explanations, Support, and Demonstrations****:* Demonstrate problems steps and provide hints, prompts, and cues for successful problem completion. Provide explanations, elaborations, and clarifications where requested.

7. ***Multiple Viewpoints****:* Foster explanations, examples, and multiple ways of understanding a problem or difficult material. Build a broad community of audiences beyond the instructor.

8. ***Collaboration and Negotiation****:* Foster student collaboration and negotiation of meaning, consensus building, joint proposals, prosocial behaviors, conflict resolution, and general social interaction.

9. ***Learning Communities****:* Create a classroom ethos or atmosphere wherein there is joint responsibility for learning, students are experts and have learning ownership, meaning is negotiated, and participation structures are understood and ritualized. Technology and other resource explorations might be used to facilitate idea generation and knowledge building within this community of peers. Interdisciplinary problem-based learning and thematic instruction in incorporated wherever possible.

10. **Assessment**: Focus of assessment is on team as well as individual participation in socially organized practices and interactions. Educational standards are socially negotiated. Embed assessment in authentic, real-world tasks and problems with challenges and options. Focus on collaboration, group processing, teamwork, and sharing of findings. Assessment is continual, less, formal, subjective, collaborative, and cumulative.

Brain-Based (Natural) Learning Principles
(Caine, Caine, McClintic & Klimek, 2005)

Caine and Caine (2007) conclude that "Optimizing the use of the human brain means using the brain's infinite capacity to make connections–and understanding what conditions maximize this process." They identify three interactive and mutually supportive elements that should be present in order for complex learning to occur: "relaxed alertness," "orchestrated immersion," and "active processing."

- An optimal state of mind that we call **relaxed alertness**, consisting of low threat and high challenge.
- The **orchestrated immersion** of the learner in multiple, complex, authentic experience.
- The regular, **active processing** of experience as the basis for making meaning.

By addressing the twelve principles of Brain-Based Learning (BBL), educators and instructional designers create the three conditions necessary for complex learning to occur.

Relaxed Alertness:
1. Principle 11: Complex learning is enhanced by challenge and inhibited by threat associated with helplessness and fatigue.
2. Principle 2: The brain/mind is social.
3. Principle 3: The search for meaning is innate.
4. Principle 5: Emotions are critical to patterning.

Orchestrated Immersion in Complex Experience:
7. Principle 6: The brain/mind processes parts and wholes simultaneously.
8. Principle 1: All learning engages the physiology.
9. Principle 4: The search for meaning occurs through patterning.
10. Principle 10: Learning is developmental.

Active Processing:
11. Principle 9: There are at least two approaches to memory. One is to store or archive isolated facts, skills, and procedures. The other is to simultaneously engage multiple systems in order to make sense of experience.
12. Principle 7: Learning involves both focused attention and peripheral perception.
13. Principle 8: Learning is both conscious and unconscious.
14. Principle 12: Each brain is uniquely organized.

Principles of Brain-Based Learning
(Jensen, 2005)

Several brain-based learning principles drive Jensen's work. Another person might come up with a different list and still be correct. Not everyone agrees on these principles or on the brain-based learning strategies that can be inferred from the principles.

1. **Malleable memories.** Memories are often not encoded at all, encoded poorly, changed ornot retrieved. The result is that students rarely remember what we think they should. Memories are susceptible to inattention, erosion over time, subject bias, misattribution and a host of other confounding conditions. Memories are strengthened by frequency, intensity and practice under varying conditions and contexts.
2. **Non-conscious experience runs automatic behaviors**. The complexity of the human body requires that we automate many behaviors. The more we automate, the less we are awareof them. Most of our behaviors have come from either "undisputed downloads" from our environment or repeated behaviors that have become automatic. This suggests potential problems and opportunities in learning.
3. **Reward and addiction dependency**. Humans have a natural craving for positive feelings, including novelty, fun, reward and personal relationships. There is a natural instinct tolimit pain even if it means compromising our integrity. For complex learning to occur, students need to defer gratification and develop the capability to go without an immediatereward.
4. **Attentional Limitations**. Most people cannot pay attention very long, except during flow states, because they cannot hold much information in their short-term memory. It is difficult for people to maintain focus for extended periods of time. We are born with the capacity to orient and fixate attention when it comes to contrast, movement, emotions or survival. But classroom learning requires a level of learned attention and many teachers don't know howto teach this skill. Adapting the content to match the learner provides better attention and motivation to learn.
5. **Brain seeks and creates understanding**. The human brain is a meaning-maker and meaning seeker. We assign value and meaning to many everyday occurrences whether it's on intentional or not. Meaning-making is an important human attribute that allows us to predict and cope with experiences. The more important the meaning, the greater the attention one must pay in order to influence the content of the meaning.
6. **Rough Drafts/Gist Learning**. Brains rarely get complex learning right the first time.Instead they often sacrifice accuracy for simply developing a "rough draft" of the learning material. If, over time, the learning material maintains or increases in its importance and relevance,the brain will upgrade the rough draft to improve meaning and accuracy. To this end, prior knowledge changes how the brain organizes new information. Goal-driven learning proceeds more rapidly than random learning. Learning is enhanced by brain mechanisms with contrasting output and input goals.

7. **Input Limitations.** Several physical structures and processes limit one's ability to take in continuous new learning. The "slow down" mechanisms include the working memory, the synaptic formation time for complex encoding and the hippocampus. While we can expose our brain to a great deal of information in a short time frame, the quality of that exposure is known as "priming" and is not considered in-depth learning. Schools typically try to cram as much content as possible in a day as possible. You can teach faster, but students will just forget faster.
8. **Perception influences our experience**. A person's experience of life is highly subjective. Many studies show how people are easily influenced to change how we see and what we hear, feel, smell and taste. This subjectivity alters experience, which alters perception. When a person changes the way they perceive the world, they alter their experience. It is experience that drives change in the brain.
9. **Malleability/Neural Plasticity**. The brain changes every day and more importantly, we influence those changes. New areas of brain plasticity and overall malleability are regularly discovered. It is known that experience can drive physical changes in the sensory cortex, frontal lobes, temporal lobes, amygdala and hippocampus. In addition whole systems can adapt to experience such as the reward system or stress response system.
10. **Emotional-Physical State Dependency**. Nearly every type of learning includes a "go" or "no go" command to the brain in our neural net signaling process. These complex signals are comprised of excite or suppress signals. Emotions can provide the brain's signals to either move ahead or not. Thus, learning occurs through a complex set of continuous signals which inform your brain about whether to form a memory or not. Both emotional and bodily states influence our attention, memory, learning, meaning and behavior through these signaling systems.

Brain Rules

(Medina, 2014)

In Brain Rules, Dr. John Medina, a molecular biologist, shares his lifelong interest in how the brain sciences might influence the way we teach adults and children, and the way we work. He describes 12 brain rules: What scientists know about how our brains work.

1. **Survival:** The human brain evolved. The brain is a survival organ. It is designed to solve problems related to surviving in an unstable outdoor environment. The strongest brains survive, not the strongest bodies
2. **Exercise:** Exercise boosts brain power. The human brain evolved under conditions of almost constant motion. From this, one might predict that the optimal environment for processing information would include motion.
3. **Sleep:** Sleep well, think well. When we're asleep, the brain is not resting at all. It is almost unbelievably active! Loss of sleep hurts attention, executive function, working memory, mood, quantitative skills, logical reasoning, and even motor dexterity.
4. **Stress:** Stressed brains don't learn the same way. Your brain is built to deal with stress that lasts about 30 seconds. The brain is not designed for long term stress when you feel like you have no control. You can actually watch the brain shrink.
5. **Wiring:** Every brain is wired differently. What YOU do and learn in life physically changes what your brain looks like – it literally rewires it. We used to think there were 7 categories of intelligence, but may number more than 7 billion.
6. **Attention:** We don't pay attention to boring things. What we pay attention to is profoundly influenced by memory. Our previous experience predicts where we should pay attention. Culture matters too.
7. **Memory:** Repeat to remember. The brain can only hold about seven pieces of information for less than 30 seconds! To extend the 30 seconds to a few minutes or even an hour, you will need to consistently re-expose yourself to the information.
8. **Sensory Integration:** Stimulate more of the senses. Our senses work together! Those in multisensory environments always do better than those in unisensory environments.
9. **Vision:** Vision trumps all other senses. We are incredible at remembering pictures. Our brain sees words as lots of tiny pictures, and we have to identify certain features in the letters to be able to read them. That takes time.
10. **Music:** Study or listen to boost cognition. Ideas about how music affects the brain long have been the providence of anecdote. But the research has been maturing for a while now.
11. **Gender:** Male and female brains are different. By more than 2 to 1, women are more likely to get depressed than men, a figure that shows up just after puberty and remains stable for the next 50 years. Males exhibit more antisocial behavior.
12. **Exploration:** We are powerful and natural explorers. The desire to explore never leaves us despite the classrooms and cubicles we are stuffed into. We learn, not by passive reaction to the environment but by active testing through observation, hypothesis, experiment, and conclusion.

First Principles of Instruction
(Merrill, 2013)

Regardless of model or method, instructional design theories, models and research indicate that instruction to address the following principles to facilitate learning.

Principle 1: Demonstration Principle. Instruction should: (a) provide a demonstration of the skill consistent with the type of component skill (i.e., kinds of, how-to, and what-happens); (b) provide guidance that relates demonstration to generalities; (c) engage learners in peer discussion and peer demonstration; and (d) allow learners to observe demonstration through media that are appropriate to the content.

Principle 2: Application Principle. Instruction should: (a) have learners apply learning consistent with the type of component skill (i.e., kinds of, how-to, and what-happens); (b) provide intrinsic or corrective feedback; (c) provide coaching, which should be gradually withdrawn to enhance application; and (d) engage learners in peer collaboration.

Principle 3: Task-Centered Principle. Instruction should (a) use a task-centered instructional strategy, and (b) use progression of increasingly complex whole tasks.

Principle 4: Activation Principle. Instruction should: (a) activate relevant cognitive structures in learners by having them recall, describe or demonstrate relevant prior knowledge of experience; (b) have learners share previous experiences with each other; and (c) have learners recall or acquire a structure for organizing new knowledge.

Principle 5: Integration Principle. Instruction should: (a) integrate new knowledge into learners' cognitive structures by having them reflect on, discuss, or defend new knowledge or skills; (b) engage learners in peer critiques; (c) have learners create, invent, or explore personal ways to use their new knowledge or skill; and (d) have learners publicly demonstrate their new knowledge.

How People Learn: Brain, Mind, Experience and School
(Bransford, Brown & Cocking, 2000)

Scientists and practitioners recognize that understanding learning requires multiple approaches that span multiple disciplines. ***The Science of Learning*** is an approach that recognizes the value and importance of cross-fertilization across traditional fields of study, including cognitive science, educational psychology, computer science, anthropology, sociology, information sciences, neurosciences, education, design studies, and instructional design. In How People Learn, Bransford, Brown, and Cocking (2000) synthesize research from the "the learning sciences" to understand how learning occurs, and posit three basic findings and four related implications with the ultimate goal of optimizing learning for all.

Findings

1. Students have preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information, or learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in any area, students must: (a) have a deep foundation offactual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and
    a. (c) organize knowledge in ways that facilitate retrieval and application.
3. A "metacognitive" approach to instruction can help students learn to take control of their own learning bydefining learning goals and monitoring their progress in achieving them.

Implications

1. Be learner centered (e.g. attend to students' prior KSAs and theories, culturaldifferences, individual progress, difficulty level).
2. Pay attention to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like (application andtransfer).
3. Facilitate formative assessments (ongoing assessments that make students' learning and thinking visible) and development of metacognitive skills.
4. Consider community (people and places that affect/support learning).

Make it Stick: The Science of Successful Learning
(Brown, Roediger, McDaniel, 2014)

The authors state that learning occurs through *encoding* (converting sensory perceptions to meaningful representations in the brain referred to as memory traces), *consolidation* (strengthening mental representations by reorganizing and stabilizing memory traces for long-term memory), and *retrieval* (knowledge recall based on context, recent use, and the number and vividness of cues). However, they suggest that strategies to facilitate learning are often misunderstood. For instance, the notion that when students learn better when they receive instruction in their preferred learning style is not supported by empirical research.

When learning gets harder and slower, students are often drawn to strategies that feel more fruitful, but knowledge gained from rereading, massed practice, and repetition (alone) disappear quickly, and can be deceptive, creating a false sense of mastery. Learning faster and easier (e.g., from high yield experiences) is not necessarily better. Learning is deeper and more durable when it is effortful. The authors propose learning principles by translating cognitive science research into evidence-based strategies that "make it stick."

1. **Practice retrieving new learning from memory**. Recalling facts, concepts, motor skills, problem-solving, and other events from memory is a potent learning tool. A quiz after reading or listening to a lecture produces better learning than rereading or reviewing lecture notes. Self-made flashcards and instructor-prepared tests help students monitor progress, spotting gaps and misconceptions that can be corrected through adaptive instruction.

2. **Space out retrieval practice.** Repeated, periodic practice requires reconstruction of memory that reinforces meaning, arrests forgetting, strengthens connections to prior knowledge, enhances retention, and bolsters cues and retrieval. Corrective feedback keeps students from incorrectly retaining information that may have been misunderstood. Delayed feedback produces better long-term learning than immediate feedback.

3. **Interleave practice and the study of different problems**. Interleaving practice of two or more subjects or skills (e.g., mixing problem types, performance requirements, and procedures) engages different parts of the brain, develops discrimination skills, and feels more difficult and less productive but the effort produces longer lasting learning and better transfer.

4. **Elaborate on new materials to formulate additional layers of meaning**. Giving new material meaning by expressing it in individualized terms and connecting it with prior knowledge, improves memory and develops mental cues that facilitate retrieval. Extracting underlying principles or rules that differentiate types of problems help identify the right solutions in unfamiliar situations.

5. **Reflect on learning to elaborate and practice retrieval**. Reflection is a form of practice that involves several cognitive activities that lead to stronger learning: retrieving knowledge from memory, connecting prior knowledge to new experiences, and visualizing and mentally rehearsing future performance enables better learning.

6. **Generate solutions before being shown the answer**. Struggling with problem solving primes the brain for better learning and retention. Learn from authentic experiences by setting out to accomplish a task, wading through the unknown and puzzling through problems using creativity and prior knowledge to generate and test potential solutions.

7. **Calibrate knowledge with objective feedback to avoid illusions of mastery.** Mistaking fluency with text information for mastery of underlying concepts is a common illusion that limits versatility and transfer. All new learning requires a foundation of prior knowledge. Assess, and if necessary, remediate prior knowledge to ensure access of the pre-requisites necessary to learn.

8. **Embrace difficulties**. Retrieval from short-term memory with little chance of error is an ineffective learning strategy. Effortful practice forms mental models that fuse interrelated ideas, and intellectual and motor skills into a meaningful whole that can be adapted and applied in varied circumstances. Retrieval difficulties posed by interleaving practice at different times, in different context, with different materials build interconnected knowledge networks that broaden mastery, foster conceptual learning, update multiple retrieval cues, and facilitate transfer.

9. **Avoid undesirable difficulties.** Fear of failure and chronic failure may inhibit learning by creating anxiety, an aversion to experimentation and risk-taking, and feelings of incompetence. Impediments that cannot be overcome are not desirable and may lead to learned helplessness. Constructive failure may motivate learning, promote persistence and resilience, and enhance memory by stimulating emotions.

10. **Use and formulate mnemonics.** Mnemonic devices hold information in memory, cued for ready retrieval. Memory palaces is a complex mnemonic device that organize and hold more information in memory by associating mental images with a series of physical locations to cue memories. Imagery and visual mnemonics are effective because pictures are memorable.

Applying the Science of Learning to the University and Beyond:
Teaching for Long-Term Retention and Transfer
(Halpern & Hakel, 2003)

Based on the premise that the first and only goal of colleges and universities is to teach for long-term retention, and transfer, Halpern and Hakel (2003) posit 10 basic laboratory tested principles that are said to be drawn from what we know about human learning. The following principles are excerpted verbatim from Halpern and Hakel (2003, p. 38-41).

1. ***The single most important variable in promoting long term retention and transfer is "practice at retrieval."*** Learners need to generate responses, with minimal cues, repeatedly over time with varied applications so that recall becomes fluent and is more likely to occur across different contexts and content domains. Information that is frequently retrieved becomes more retrievable; the strength of the "memory trace" for any information that is recalled grows stronger with each retrieval.

2. ***Varying the conditions under which learning takes place makes learning harder for learners but results in better learning.*** When learning occurs under varied conditions, key ideas have "multiple retrieval cues" and thus are more "available" in memory.

3. ***Learning*** **is** ***generally enhanced when learners are required to lake information that is presented in one format and "re-represent" it in an alternative format.*** Humans process information by means of two distinct channels-one for visuospatial information and one for auditory-verbal information. Information that is represented in both formats is more likely to be recalled than information that is stored in either format alone.

4. ***What and how much is learned in any situation depends heavily on prior knowledge and experience.*** Learners create new meaning using what he or she already knows. Thus, the best predictor of what is learned at the completion of any lesson, course, or program of study is what the learner thinks and knows at the start of the experience.

5. ***Learning is influenced by both our students' and our own epistemologies.*** Determining the best way for students to learn and recall something will thus depend on *what* you want learners to learn and be able to recall, what they *already know,* and their *own beliefs* about the nature of learning.

6. ***Experience alone is a poor teacher.*** Research in metacognition has shown that most people are poor judges of how well they comprehend a complex topic. Systematic and corrective feedback about the consequences of various actions is essential for facilitating experiential learning.

7. ***Lectures work well for learning assessed with recognition tests, but work badly for understanding.*** Understanding is an *interpretive* process in which students must be active participants. Learners need ''cues'' that trigger interpretation and force them to engage the material actively. The combination of large lecture classes and multiple choice tests constitutes a relatively low-cost approach to instruction but typically does not require learners to actively process information.

8. ***The act of remembering itself influences what learners will and will not remember in the future.*** Asking learners to recall particular pieces of the information they've been taught often leads to "selective forgetting" of related information that they were nor asked to recall. Frequent testing also leads to overconfidence for learners who erroneously believe that their long-term retention of the information will be better than it actually is.

9. ***Less is more, especially when we think about long-term retention and transfer.*** An emphasis on in-depth understanding of basic principles often constitutes a better instructional design than more encyclopedic coverage of a broad range of topics.

10. ***What learners do determine what and how much* is *learned, how well it will be remembered, and the conditions under which it will be recalled.*** "The head remembers what it does." What professors do in their classes matters far less than what they ask students to do both in and out of class.

Science of Learning
(Deans for Impact, 2015)

Founded in 2015, Deans for Impact is a national nonprofit organization representing leaders in educator preparation who are committed to transforming educator preparation and elevating the teaching profession. The organization is guided by four key values: (a) Data-informed improvement; (b) Common outcome measures; (c) Empirical validation of effectiveness; and (d) Transparency and accountability for results. The Science of Learning examines existing research from learning sciences and organizes findings into four sets of cognitive principles to connect research to its practical implications for teaching and learning.

Cognitive Principles (How do students understand and retain new ideas?)

1. Students learn new ideas by reference to ideas they alreadyknow.
2. To learn, students must transfer information from working memory (where it is consciously processed) to long-term memory (where it can be stored and later retrieved). Students have limited working memory capacities that can be overwhelmed by tasksthat are cognitively too demanding. Understanding new ideas can be impeded if students are confronted with too much information at once.
3. Information is often withdrawn from memory just as it went in. We usually wantstudents to remember what information means and why it is important, so they should think about meaning when they encounter to-be-remembered material.
4. Practice is essential to learning new facts, but not all practice isequivalent.

Cognitive Principles (How do students solve problems and transfer?)

5. Each subject area has some set of facts that, if committed to long-term memory,aids problem-solving by freeing working memory resources and illuminating contexts in which existing knowledge and skills can be applied. The size and content of this set varies by subject matter.
6. Effective feedback is essential to acquiring new knowledge andskills.
7. The transfer of knowledge or skills to a novel problem requires both knowledge ofthe problem's context and a deep understanding of the problem's underlyingstructure.
8. We understand new ideas via examples, but it's often hard to see the unifyingunderlying concepts in different examples.

Cognitive Principles (What motivates students to learn?)

9. Beliefs about intelligence are important predictors of student behavior in school.
10. Self-determined motivation (a consequence of values or pure interest) leads to better long-term outcomes than controlled motivation (a consequence of reward/punishment or perceptions of self-worth).
11. The ability to monitor their own thinking can help students identify what they do and do not know, but people are often unable to accurately judge their own learning and understanding.
12. Students will be more motivated and successful in academic environments when they believe that they belong and are accepted in those environments.

Cognitive Principles (What are common misconceptions about learning?)

13. Students do not have different "learning styles."
14. Humans do not use only 10% of their brains.
15. People are not preferentially "right-brained" or "left-brained" in the use of their brains.
16. Novices and experts cannot think in all the same ways.
17. Cognitive development does not progress via a fixed progression of age-related stages.

Learning about Learning: What Every New Teacher Needs to Know
(Pomerance, Greenberg, & Walsh, 2016)

Six strategies that are said to, "stand out for the research behind them. There is little debate among scholars about the effectiveness of these six strategies" (Pomerance, Greenberg, & Walsh, 2016, p. vi), highlight the importance of examining supporting research before adopting principles or propositions published under the pretext of the Science of Learning, Learning Science (or any class or individual theory). First, excerpts from a formal review of "Learning about Learning" is presented to note the concerns, followed by the summary of the original sources.

"As part of an ongoing series of reports by the National Council on Teacher Quality (NCTQ), Learning About Learning: What Every New Teacher Needs to Know makes broad claims about teacher education based on a limited analysis of textbooks and syllabi. The report argues that teacher education materials, specifically educational psychology and methods textbooks, are a waste of funds and do not adequately focus on what the report identifies as six essential strategies. These inadequacies, the report contends, result in ill-prepared teacher candidates lacking in "research-proven instructional strategies" (p. vi). The report offers recommendations for textbook publishers, teacher education programs, and state departments of education. However, it is not grounded in a comprehensive examination of the literature on teaching methods, and it fails to validate the evaluative criteria it employs in selecting programs, textbooks, and syllabi. The single source it relies on to justify its "six essential strategies" [Organizing Instruction and Study to Improve Student Learning: A Practice Guide, published by the Institute of Education Sciences (IES), the research arm of the U.S. Department of Education] provides limited support for NCTQ's claims. This primary source concludes, with only one exception, that the evidence supporting each of the six strategies is only moderate or weak [Table 1]. Limiting the analysis to one source that provides only tepid support renders the report of little value for improving teacher preparation, selecting textbooks, or guiding educational policy."

(Thomas & Boering, 2016, p. 1)

Table 1. NCTQ Six Strategies that Work and IES Levels of Effectiveness (Source: Organizing instruction and study to improve student learning)

NCTQ Six Strategies that Work	IES Levels of Effectiveness
pairing graphics with words	moderate
linking abstract concepts with concrete representations	moderate
posing probing questions	strong
repeating alternating problems with their solutions provided and problems that students must solve	moderate
distributing practice	moderate
assessing to boost retention	minimal

In the Review of Learning About Learning, Thomas and Boering (2016) conclude that, "Overall, the NCTQ report fails to justify the validity of its one foundational study and does not offer sufficient evidence of its methods for choosing and analyzing textbooks or course syllabi in order to reach its conclusions and recommendations. Starting with a different (and defensible) set of what teaching strategies work and then analyzing different programs and textbooks would likely produce different conclusions and recommendations. Failing its own criteria of grounding teacher preparation in research, the NCTQ guide is not an appropriate framework for analyzing the complex nature of how people learn or how teachers should teach, especially across all grade levels and content areas. From our perspective as English teachers and English educators, for example, we would not engage students in repeating alternating problems with their solutions provided and problems that students must solve" (p. 6).

What were the original strategies and how have they evolved?

In Organizing Instruction and Study to Improve Student Learning: A Practice Guide, the research arm of the U.S. Department of Education—the IES—originally distilled seven recommendations for promoting learning for all students, regardless of grade or subject, and that were said to be especially potent with struggling students, including: (1) space learning over time, (2) interleave worked examples solutions and problem-solving exercises, (3) combine graphics with verbal descriptions, (4) connect and integrate abstract and concrete representatives of concepts, (5) use quizzing to promote learning, (6) help learners allocate study time effectively, and (7) help students build explanations by asking and answering deep questions (Pashler et al. 2007).

Then, without explanations, the authors of the NCTO report changed the seven recommendations into six strategies (summarized below), that were then used to analyze 48 textbooks obtained from 48 teacher preparation programs to determine how well the text addressed the strategies. Based on the low percentage of textbooks that were found to address each strategy (ranging from 0% to 41%), the NCTQ report concluded that, "publishers and authors are failing both aspiring teachers and the teaching profession. They are not ensuring that the core texts designed to produce our next generation of teachers are giving candidates the most fundamental information needed to make learning "stick." The transfer of knowledge — from researchers to publishers to teacher educators to aspiring teachers — is not happening while the need to impart it has never been more urgent" (p. v).

The six strategies reported by NCTO (Pomerance, Greenberg, & Walsh, 2016)

The first two help students take in new information:

1. Pairing graphics with words. Young or old, all of us receive information through two primary pathways — words and graphic or pictorial representations. Student learning increases when teachers convey new material through both.
2. Linking abstract concepts with concrete representations. Teachers should present tangible examples that illuminate overarching ideas and also explain how the examples and big ideas connect.

The second two ensure that students connect information to deepen their understanding:

3. Posing probing questions. Asking students "why," "how," "what if," and "how do you know" requires them to clarify and link their knowledge of key ideas.
4. Repeatedly alternating problems with their solutions provided and problems that students must solve. Explanations accompanying solved problems help students comprehend underlying principles, taking them beyond the mechanics of problem solving.

The final two help students remember what they learned:

5. Distributing practice. Students should practice material several times after learning it, with each practice or review separated by weeks and even months.
6. Assessing to boost retention. Beyond the value of formative assessment (to help a teacher decide what to teach) and summative assessment (to determine what students have learned), assessments that require students to recall material help information "stick."

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Additional Resources on the Science of Learning

- Johns Hopkins University - Science of Learning (http://scienceoflearning.jhu.edu/)
- What is the Science of Learning (SoL) (50:04) (https://www.youtube.com/watch?v=bH6TgMM9VME)
- The New Brain Science of Learning (27:42) (https://www.youtube.com/watch?v=ahSYwchh-QM)
- SoL: How to Turn Information into Intelligence (8:26) (https://www.youtube.com/watch?v=1FvYJhpNvHY)
- The Science of Thinking (12:09) (https://www.youtube.com/watch?v=UBVV8pch1dM)

- Neuroscience, the SoL, and Educational Reform (1:34:20) (https://www.youtube.com/watch?v=y-bZidebHmA)
- The New SoL: How to Learn in Harmony with your Brain (1:50:16) (https://www.youtube.com/watch?v=7RA6ysY4FVQ)
- Want children to pay attention? Make their brains curious (23:09) (https://www.youtube.com/watch?v=ARymnvIsies)