CHAPTER 4

Applying Cognitive Science to Online Teaching and Learning Strategies

This chapter lays out twenty-five universal principles of learning derived from cognitive psychological research, one of which has several corollaries that apply directly to online learning. These principles focus on how well students learn and remember new material. We then derive the implications of these principles for online course design and teaching. These implications suggest dozens of best practices for designing an online course, organizing and presenting its content, helping students develop skills, deciding on teaching and assessment methods, incorporating social interaction, and providing students with feedback.

The greatest promise of learning technology is not in doing what we have always done better, faster, or more cheaply but rather in providing the kinds of learning experiences that would be impossible without technology.

—B. Means, M. Bakia, and R. Murphy (2014)

TWENTY-FIVE PRINCIPLES OF LEARNING FROM COGNITIVE SCIENCE

Some principles of learning apply universally to the human mind. (Many of these apply to the minds of other species as well.) They transcend the environment, the technology, the setting, student demographics, and instructor characteristics. They go beyond course content and focus more on how students receive and work with that content. Indeed, they drive and sustain the whole process of learning. Therefore, they should guide online course design, treatment of the content, selection of teaching and assessment methods, and feedback to students.

When online learning surpasses classroom learning, it is not the technology itself but the course design, time on task, and student engagement with the content that account for the better outcomes (Means, Bakia, & Murphy, 2014). These findings hold even for courses with rich media, which can interfere with learning if overdone, misaligned, or poorly designed (Mayer, 2009).

Cognitive psychological research has generated or supported all of the following principles. Multimedia research and the teaching and learning literature have produced several corollaries of these principles.

1. Students learn procedures and processes best when they learn the steps in the same order that they will perform them (Feldon, 2010).
2. Students learn new material better and can remember it longer when they learn it by engaging in an activity than when they passively watch or listen to an instructor talk (Bligh, 2000; Bonwell & Eison, 1991; Deslauriers, Schelew, & Wieman, 2011; Hake, 1998; Jones-Wilson, 2005; Spence, 2001; Svinicki, 2004; Swiderski, 2005). Because interacting with others demands active engagement, we add this corollary from Persellin and Daniels (2014), even though it derives from the classroom-based teaching and learning literature rather than cognitive psychology: small-group work and discussion engage students, allowing them to construct knowledge actively on their own (Stage, Kinzie, Muller, & Simmons, 1999).
3. Students learn from practice, but only when they receive targeted feedback that they can use to improve their performance in further practice (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). Of course, they must first read and accurately interpret that feedback, which they do not always do (Falkenberg, 1996).
4. Students relate new material to their prior knowledge about it, which highlights the importance of the validity and the organization of that prior knowledge (Ambrose et al., 2010; Baume & Baume, 2008; Bransford, Brown, & Cocking, 1999; Taylor & Kowalski, 2014).
5. Students learn best and most easily when they feel they are in a safe, low-stress, supportive, welcoming environment (Ambrose et al., 2010; Doyle & Zakrajsek, 2013). They are more likely to achieve the learning outcomes of the course, develop higher-order thinking skills, participate in class activities, behave appropriately in class, be motivated to learn, and be satisfied with the course, whether classroom based (Cornelius-White, 2007; Granitz, Koernig, & Harich, 2009) or online (Lundberg & Sheridan, 2015).
6. Some qualities attract and hold students' attention and focus and therefore help students learn new material better and remember it longer: human faces, color, intensity, extreme contrasts, movement, change, drama, instructor enthusiasm, and personal relevance (Ambrose et al., 2010; Bransford et al., 1999; Hobson, 2002; Persellin & Daniels, 2014; Svinicki, 2004; Winne & Nesbit, 2010).
7. Students learn and store new material—that is, move it from working memory into long-term memory—through *elaborative rehearsal*, which means thinking about the meaning and importance of the new material and connecting it to their prior knowledge, beliefs, and mental models (Ambrose et al., 2010; Bransford et al., 1999; Tigner, 1999; Zull, 2002).
8. Students learn new material most easily when the instruction is designed to minimize cognitive load (Feldon, 2010; Sweller, van Merriënboer, & Paas, 1998; Wickens, 2002, 2008; Winne & Nesbit, 2010). By *cognitive load*, we mean the demands placed on working memory. The mind has a limited capacity to hold information in working memory, so it is important to package information for the most efficient processing possible. This principle is very general but has subprinciples that will clarify its meaning (see the next section).

9. Students learn new material better and can remember it longer when they receive it multiple times and in different ways—that is, through multiple senses and in multiple modes that use different parts of their brain—than when they receive it just once or multiple times in the same way (Doyle & Zakrajsek, 2013; Hattie, 2009; Kress, Jewitt, Ogborn, & Charalampos, 2006; Shams & Seitz, 2008; Tulving, 1967, 1985; Vekiri, 2002; Winne & Nesbit, 2010; Zull, 2002, 2011). Learning styles seem not to exist. Numerous studies have found that teaching to a person's style fails to improve his or her learning over teaching to other styles (Howard-Jones, 2014; Pashler, McDaniel, Rohrer, & Bjork, 2008).
10. Students learn new material better and can remember it longer when they receive it in an organized structure or when they organize and structure it themselves (if they are ready to do so). In fact, the only way people remember anything long term is in a coherent, logically organized structure based on patterns and relationships among interconnected parts. Without a coherent big picture of prior knowledge in their minds, students cannot comprehend and retain new material (Ambrose et al., 2010; Bransford et al., 1999; Hanson, 2006; Svinicki, 2004; Wieman, 2007). Structures are shown most clearly in graphics, which also serve as retrieval cues.
11. Students learn new material better and can remember it longer when they receive it in connection with easy-to-understand stories and example cases (Bower & Clark, 1969; Graesser, Olde, & Klettke, 2002; Haberlandt & Graesser, 1985).
12. Students learn new material better and can remember it longer when they receive it in connection with a number of examples that vary by content, conditions, discipline, and level of abstraction (Hakel & Halpern, 2005).
13. Students learn new material better and can remember it longer when the material evokes emotional and not just intellectual or physical involvement. This principle mirrors the biological base of learning, which is the close communication between the frontal lobes of the brain and the limbic system. From a biological point of view, learning entails changes in the brain in which new or fragile synapses are formed or strengthened (Leamnson, 1999, 2000; Zull, 2002, 2011).
14. Students learn new material better and can remember it longer when they review or practice new material at multiple, intervallic times than when they review it all at one time (Brown, Roediger, & McDaniel, 2014; Butler, Marsh, Slavinsky, & Baraniuk, 2014; Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Hattie, 2009; Rohrer & Pashler, 2010; Winne & Nesbit, 2010). This schedule of practice is called "spaced" or "distributive," and it can take the form of being tested or self-testing (see item 17 in this list).
15. Students learn new material better and can remember it longer when that review or practice is "interleaved" than when it is "blocked." In other words, students benefit when they occasionally review earlier material as they are learning new material (Butler et al., 2014; Dunlosky et al., 2013; Rohrer & Pashler, 2010).
16. Students learn new material better and can remember it longer when they actively and effectively plan, monitor, and evaluate their learning (self-regulated learning). This means observing their cognitive learning strategies (metacognition), emotional reactions to the material, and physical reactions to their learning environment (Ambrose et al., 2010; Bransford et al., 1999; Hattie, 2009; Nilson, 2013; Winne & Nesbit, 2010; Zimmerman, Moylan, Hudesman, White, & Flugman, 2011).
17. Students learn new material better and can remember it longer when they are tested or test themselves on it than they do when they just reread it (even multiple times), as the former involves retrieval practice and more effortful cognitive processing (see item 14) (Brown et al., 2014; Dempster, 1996, 1997; Dunlosky et al., 2013; Karpicke & Blunt, 2011; McDaniel, Howard, & Einstein, 2009; Roediger &

Karpicke, 2006; Rohrer & Pashler, 2010; Rohrer, Taylor, & Sholar, 2010; Winne & Nesbit, 2010). This is called the *testing effect*.

18. Students can remember material longer after repeated testing when they expect a final comprehensive exam. They will keep material more accessible in memory when they expect to have to recall it in the future than when they do not (Szupnar, McDermott, & Roediger, 2007).
19. Students learn new material better and can remember it longer when they have to produce answers and not just recognize correct ones—that is, when they expect to have to free-recall material for short answer or essay questions (Butler & Roediger, 2007; McDaniel, Anderson, Derbish, & Morrisette, 2007; Tulving, 1967). This is called the generation effect.
20. Students learn new material better and can remember it longer when they have to work harder to learn it—that is, when they have to overcome what are called *desirable difficulties* (Bjork, 1994, 2013; Bjork & Bjork, 2011; Brown et al., 2014; McDaniel & Butler, 2010). These difficulties can help students generate multiple retrieval paths and stretch their abilities.
21. Students learn new material better when it creates impasses in their current mental models—that is, contradictions, conflicts, anomalies, uncertainties, and ambiguities, which stimulate curiosity, inquiry, questioning, problem solving, and deep reasoning to restore "cognitive equilibrium" (Chinn & Brewer, 1993; Graesser & McMahen, 1993; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005; Graesser & Olde, 2003).
22. Students understand new material better when instructors train them to ask deep thinking and explanation questions such as *why, how,* and *what if* as opposed to simple recall questions (Craig, Sullins, Witherspoon, & Gholson, 2006; Graesser & Person, 1994; Rosenshine, Meister, & Chapman, 1996).
23. Students learn new material better and can remember it longer when they can correct and learn from errors. Research on mice has revealed a biological base: when an organism gets an error signal, its brain releases calcium, which enhances the brain's ability to learn and change, that is, its *neuroplasticity* (Najarfi, Giovannucci, Wang, & Medina, 2014).
24. Students learn from their mistakes more effectively when they receive immediate feedback on an assignment, quiz, or test (Anderson, Corbett, Koedinger, & Pelletier, 1995; McTighe & O'Connor, 2005; Roediger & Marsh, 2005; Shute, 2006).
25. Students learn new material better and can remember it longer when they read it from printed text than from e-textbooks and websites (Baron, 2015; Daniel & Willingham, 2012; Daniel & Woody, 2013; Kolowich, 2014; Mangen, Walgermo, & Brønnick, 2012; Sanchez & Wiley, 2009; Tanner, 2014; Wästlund, Reinikka, Norlander, & Archer, 2005; Zhang, Yan, Kendrick, & Li, 2012).

HOW THESE PRINCIPLES CAN INFORM ONLINE COURSE DESIGN AND TEACHING

Some of these principles have ramifications for teaching that are quite straightforward, but the practical meaning of others is not quite so clear.

Principle 1: The Sequence of Procedural and Processual Steps

The teaching implications of this principle are obvious for all platforms: when designing and teaching a course, make sure to sequence the steps of a procedure and process in the same order that students will perform them. The Khan Academy provides many examples of this strategy for teaching problem-solving procedures in its online videos (Murphy, Gallagher, Krumm, Mislevy, & Hafter, 2014).

Principle 2: Active Learning

Just about any student-active teaching method that works well in a traditional classroom environment supports active engagement in an online course. Whatever the platform, students learn more when given opportunities for reflective writing (Means et al., 2014; US Department of Education, 2010), student-to-student interaction (Carr, Gardner, Odell, Munsch, & Wilson), and group work such as jigsaw (Huang, Huang, & Yu, 2011; Shaaban, 2006). Other activities that engage students include these (Eberlein et al., 2008; Nilson, 2016):

- Quizzes
- Interviews
- Surveys
- Debates and constructive controversy, which can foster critical analysis and evaluation
- Interactive videos, especially those that integrate questions and reflection prompts
- Interactive learning objects
- Blogs
- Group projects
- Wikis
- Well-moderated discussions, especially those that incorporate elements of self-reflection and self-evaluation
- Process-oriented guided inquiry learning in science courses (POGIL)
- Peer-led team learning in math and sciences (PLTL)
- The case method and problem-based learning (PBL)
- Role plays, which can encourage understanding of different perspectives
- Simulations followed by debriefing
- Expert panels to which students ask questions

These methods allow students to construct knowledge collaboratively and adapt well to discussion boards, wikis, and GoogleDocs, both whole class and small group. Chapter 6 offers more on these and other active learning techniques.

Principle 3: Targeted Feedback

To provide targeted feedback, the assessment criteria must first clearly delineate what a student product should accomplish, what elements it should contain, and what questions it should answer. In addition, students must understand the criteria, so it is best to furnish models and set up a discussion thread on just the criteria. Targeted feedback means focusing on helping students improve their performance in the next similar assessment and telling them what they are doing well. This type of feedback is constructive, improvement directed, and process centered (Means et al., 2014), and research confirms that it enhances student performance and pass rates in online courses (Bonnel & Boehm, 2011; Gosmire, Morrison, & Van Osdel, 2009; Ley & Gannon-Cook, 2014; Online Learning Consortium, 2016; Shaw, 2013). It is not surprising that online students greatly value timely and informative feedback (Northrup, 2011; Yuan & Kim, 2015).

Targeted feedback zeros in on how students can close the gap between their current and the desired performance, whether an art project, computer program, statistical analysis, physics demonstration, chemistry experiment, mathematical problem solution, writing assignment, or other project. It emphasizes what

students have to learn now and may set a specific target for their next assignment (Coffield with Costa, Müller, & Webber, 2014; Duncan, 2007). Give praise where deserved because students may not know what they are doing right. But focus on praising the effort and the process students went through to produce the work to help ensure they keep putting forth the necessary effort (Coffield et al., 2014; Dweck, 2007; Halvorson, 2014). No one excels by sitting on their laurels.

On objective quizzes and tests, most learning management systems (LMSs) allow you to preload feedback for correct and incorrect answers—for example, for an incorrect response: "Social Anxiety Disorder is not the best choice. Please refer to . . ." and for a correct response: "Yes! Body Dysmorphic Disorder is the correct label for . . ." Such feedback is simple to prepare yet often neglected. You can also set the timing of the feedback to be immediate or delayed until all students have submitted the same quiz or test.

For essays and papers, your comments should concentrate on major writing issues such as content, reasoning, and organization, and less on style and grammar. If your feedback fails to improve a student's performance, consider giving the student additional clarification and models to help him or her understand and implement your feedback (Falkenberg, 1996; Means et al., 2014; Wiggins, 2012). If possible, provide feedback in multiple forms using freely available technology tools, such as highlighting and adding comments on a student's file and supplementing your written feedback with Skype, FaceTime, VoiceThread, or a telephone call (Yuan & Kim, 2015). Avoid social media to keep the feedback private.

Consider making a follow-up assignment in which students paraphrase or summarize your feedback back to you. This way, they have to review all of your feedback carefully and make sense of it (Nilson, 2013). We in turn can find out how our students interpret our comments and corrections and will be able to clarify what they misunderstand. Perhaps the words, symbols, and abbreviations we use are alien or ambiguous to them. Only when students attend to and accurately understand our feedback can we expect them to improve their work. When students will revise a piece of work, have them write out their goals and plans for revision and explain the changes they plan in response to the feedback they have received (Nilson, 2013).

Feedback can come from several sources and use several media:

- *You:* Individual e-mails or Skype or FaceTime sessions for private communication such as comments on assignments; affirmation to students on track; tips to those off track on how to improve or catch up; e-mail announcements or feedback to groups or the whole class; reflective summaries or "my thoughts" after students have discussed an issue; discussion board postings to a group or the whole class; recorded audio or video; embedded feedback in study and quiz tools; feedback templates and rubrics accompanying submitted work; additional comments on a rubric; error analyses; additional practice; or more modeling of correct strategies for incorrect problem solutions (Means et al., 2014)
- *Fellow students:* Through replies from classmates in discussion forums; in response to nonevaluative prompts that ask for identification of required elements in the work or reactions (Nilson, 2003); on a team evaluation form in which students assess their own contributions as well as those of their teammates (Goodson, 2004a; Leader, 2002)
- *External experts:* Invited into a discussion or chat space for a specific purpose and time frame (Bonk, 2013; Goodson, 2004b)
- *Programmed software:* Student self-assessments such as flash cards or readiness-reflection quizzes; preloaded, automated feedback for correct and incorrect responses to quizzes and tests; preloaded publisher feedback in quizzes and tutorials; web-based interactive learning objects that include quizzes

Principle 4: The Validity and Organization of Prior Knowledge

The mind filters all new incoming information according to its compatibility with what it also knows or thinks it knows. This means that you have to start teaching from your students' current mental models of your content. If you are not sure what those models are, you should find them out by asking your students how they think some phenomenon works or comes into being or giving them a multiple-choice test with distracters that reflect possible or likely misconceptions.

Once you know your students' mental models, you must convince them that your discipline's models provide better explanations—more robust, comprehensive, plausible, evidence based, whatever—than their faulty models (Baume & Baume, 2008; Taylor & Kowalski, 2014). If what you teach fails to fit into their models, your lessons will not stick. You can address and correct student misconceptions in a variety of ways: demonstrations, animations, videos, simulations, and even readings. Or give students opportunities to test the validity of their misconceptions (CIRTL, n.d.). (See principles 10 and 21.)

Once you know that your students have a valid mental model, relate new knowledge to their prior knowledge as much as possible. This will help them elaborate the models and more easily store the new knowledge.

Principle 5: A Safe, Welcoming Environment

At the beginning of your course, set the tone for the style of communication you expect. Get to know your students, and let them get to know you. Share some information about your professional background, your interest in the course content, and your positive feelings about teaching it. If you have posted an inviting introduction for yourself, you can assume that students who wish to respond will do so. You might also incorporate one or two social icebreakers that allow students to get acquainted with each other and begin to build a classroom community. Consider whether students might already know each other from previous courses. In any case, you can set up a discussion forum where students share information about themselves. You can ask about their geographical locations, majors or occupations, reasons for taking the course, and perhaps something they are proud of having done or become. Otherwise you can let the introductions run their course so that students can get to know each other in their own ways. Watch for occasions when it makes more sense to send a private e-mail in reply to a student's introduction.

Strive to relate to your students on a quasi-personal level. Send them positive, motivating messages every so often (see chapters 5 and 6). Show and tell them that you care about their welfare and their success in your course. In addition, show that you care about their opinions by soliciting their feedback about how the course is going on a fairly regular basis. (Chapter 6 addresses the kinds of instructor-student interaction that have the most favorable effects.)

When you set up content-focused discussion areas, keep in mind that your postings can sometimes decrease student participation (Fortner & Murphy, 2014). Your words can carry such power that they shut out student exchanges. You may want to save your additional postings for times when you need to redirect students to the right path for progress in your course. Keep your messages short with a specific purpose (Liu & Kaye, 2016; Van Voorhis & Falkner, 2004). In other words, "be actively engaged, but avoid prominence" (Helms et al., 2011, p. 65). We are responsible for creating and maintaining inclusive opportunities. When possible, integrate course content that includes the scholarly and artistic contributions and perspectives of all genders and cultural, ethnic, and racial groups. Avoid asking diverse students to represent their group. Whatever their group, it is too internally diverse to be represented by one or a few members.

Use gender-neutral language. Call a group by the name that its members prefer. Do not stay away from course-appropriate topics related to diversity because they are sensitive, controversial, or applicable to only a minority of people. Some students may see your avoidance as prejudicial.

We must also be poised to prevent and respond to disruptive, offensive discussion posts. Rather than waiting until an ill-considered post appears, have clear communication policies from the beginning of the course and advise students on how to optimize the value of their online discussions. The web offers some excellent choices—for example:

- Code of Conduct, Geek Feminism: http://geekfeminism.org/about/code-of-conduct/
- Netiquette, Virginia Shea: http://www.albion.com/netiquette/index.html
- Online Forums—Responding Thoughtfully, Jennifer Janechek, Writing Commons: http://writingcommons.org/open-text/new-media/online-forums/651-online-forums-responding-thoughtfully

Of course, you must enforce your communication policies. Early on, monitor one or two fairly low-risk discussions for insulting comments and unfounded attacks on assigned work or ideas, and privately counsel any offenders. Explain why you are concerned, what kinds of comments are more appropriate, and why. Students new to online discussions can make careless missteps such as flaming without actually realizing their negative impact, and some gentle informative guidance can put them on track. After that, enforce consequences as stated in your syllabus and institution policies against harassment. For the protection of other classmates, you may need to remove a student's offending posts or confine his or her comments to a private discussion forum or journal area (Salter, 2015).

Principle 6: Attention Attractors and Holders

Because chapters 2 and 5 treat the personal relevance of material in depth, we focus here on the implications of other attention attractors and holders.

Students cannot learn if their attention is somewhere other than the lesson. With mobile devices practically ubiquitous in the student population, this distraction problem plagues the classroom environment (McCoy, 2013; Tindell & Bohlander, 2012). Computers and mobile devices interfere with work done outside a classroom as well (Parry, 2013; Patterson, 2017), where faculty cannot monitor and restrict their use. This means that almost all online learning and assessment activities are subject to distractions.

All that you can do is to try to make content presentation as compelling as possible. Where possible, show your face. Find ways to display enthusiasm and drama. Add relevant, interesting images. Use visuals strategically, avoid dense text, and keep the cognitive load low (Daniel, 2014). In your recordings, vary your facial expressions, vocal intonations, speaking pace, and movements, even if the technology allows only hand gestures. Produce videos of your lectures in short installments, and select similarly brief videos from other sources. Students attentively watch only about six minutes of a video (Guo, Kim, & Rubin, 2014), and videos under eight minutes are the ones most viewed on YouTube (*Wired,* 2011). On occasion, however, you may want to show a really superb speech in its entirety (MiniMatters, n.d.) or show one of the professionally produced, well-coached, and well-rehearsed TED talks (www.ted.com), all of which are limited to eighteen to twenty minutes (Gallo, 2014).

Text-dense slide presentations rarely attract and hold student attention. Reserve slides for what the students need to *see*—for pictures, photographs, diagrams, and other visuals (Elder, 2009)—and supplement them with your narration (Daniel, 2014). Put dense text in Word documents with visual images added, and

save them in PDF format, which makes them faster and easier for students to open, view, and print. When you must place text on a slide or in a video, use intense colors and tasteful color contrasts, such as dark blue text on a white or yellow background or white or yellow text on a dark blue background.

In general, varying your media among videos, audio, graphics, and text helps keep your students' attention. For a broad array of possibilities, go to Cathy Moore's blog, where you will find graphics, videos, animations, simulations, cases, multimedia scenarios, and infographics, many of them interactive:

- Elearning Samples, Cathy Moore—Let's Save the World from Boring Training: http://blog.cathy-moore.com/resources/elearning-samples/

Principle 7: Elaborative Rehearsal for Long-Term Memory

To be able to recall new material long term, students must think about it while holding it in working memory. Specifically, they need to reflect on its importance, its deeper meaning, and its connection to what they already know or believe to be true. But they need inducement and time to do this. While such pauses for reflection often seem awkward in the traditional classroom, online courses offer superior opportunities for elaborative rehearsal. You can simply insert questions and prompts before, during, and after videos, podcasts, or other content presentations and collect student responses (Williams, 2013). The questions may be as simple as, "This video is about _____. What do you already know about this topic?" or, "What have you learned about why this topic is important?" Students should submit their responses, which you can grade pass or fail with a few points for pass and zero for fail (see principle 16).

Principle 8: Cognitive Load Minimized

How can you minimize the cognitive load of learning for students? This principle has several corollaries from cognitive psychology and instructional design that lay out concrete guidelines.

a. Students learn new material better and can remember it longer when they receive it in chunks that reduce the number of pieces of new information by collapsing them into categories or logical groups (Gobet et al., 2001; Hanson, 2006; Mayer & Moreno, 2003; Miller, 1956; Wieman, 2007). Therefore, try to help your students categorize and classify material whenever possible. Teach them that a concept is a category that groups similar observations and facts and thereby makes learning more efficient. Give them exercises in classifying subconcepts under more general ones, as a concept map might show—for example, "Which of these concepts is most general and is a category under which the others fall: liquid rain, freezing rain, precipitation, hail, and snow?" (Precipitation.)

b. Students learn new material better and can remember it longer when they receive a complex lesson in shorter segments rather than as one long continuous lesson (Clark & Mayer, 2011; Mayer, 2005; Mayer & Moreno, 2003). Called the *segmentation principle*, it has special importance in the online context. Any continuous exposition of content, whether videos, podcasts, or animations, needs to be divided into short segments of three to ten minutes. Even text should be segmented by headings and subheadings, and you should avoid assigning too much text at one time.

c. Students learn new material better and can remember it longer when the learning is scaffolded to build new information and skills on those previously acquired or approximated. In other words, you should design learning to be incremental, adding complexity in stages or layers. When students begin learning

something new, you need to provide the most help and hints—training wheels, if you will—which you should progressively withdraw as students practice more and progress. The following techniques illustrate the kind of scaffolding you might provide (Hmelo-Silver, Duncan, & Chin, 2007; Kirschner, Sweller, & Clark, 2006; Mayer & Moreno, 2003):

- Modeling a procedure or method of reasoning, as you might in a video or podcast
- Making models available of the work you want students to produce on the course LMS or website
- Explaining abstract content with practical examples
- Guiding students' early practice with step-by-step hints and feedback, given in either one-on-one or group communication
- Showing students worked examples (problem solutions) to start and only partially worked examples as they progress
- Launching new topics with a graphic organizer of their sequenced components

d. Students learn new material better and can remember it longer when its presentation uses both words and graphics rather than just words. This is termed the *multimedia principle* (Clark & Mayer, 2011; Mayer & Moreno, 2003), and it means that online learning should not rely on text-based presentations and readings alone. Rather, you should display graphics (e.g., pictures, photographs, diagrams, flowcharts, animations, videos, concept maps, mind maps) as much as possible to illustrate phenomena, principles, examples, processes, procedures, and causal and conceptual relationships. Of course, labels, descriptions, and explanations should accompany the graphics. In fact, students are more likely to remember graphics than words, and the graphics then cue the words. The human mind processes, stores, and retrieves visuals more easily and with less effort than it does text. Graphics facilitate thinking about the material—drawing inferences, analyzing relationships, and making new connections between elements—and do not require the elaborate cognitive transformations that written words do (Tulving, 1967, 1985; Vekiri, 2002; Zull, 2011).

e. Students learn new material better and can remember it longer when its presentation aligns words to their corresponding graphics in close proximity (Clark & Mayer, 2011). Complementing the multimedia principle (principle 8d), this contiguity principle recommends that the labeling, descriptive, or explanatory text be physically close to its accompanying graphic element.

f. Students learn new material better and can remember it longer when its presentation relies on words in an audio narration than in written text (Clark & Mayer, 2011; Moreno, 2006). This principle states that you should find or make an audio recording of online content whenever possible rather than use text alone. However, accessibility guidelines require you to make verbal material available in both audio and text formats as well as visual whenever possible (see chapter 7).

g. Students learn new material better and can remember it longer when its presentation explains the graphics with audio narration or written text but not both (Clark & Mayer, 2011). The *redundancy principle*, as it is called, advises you to have your students either listen to the audio recording or read the text that accompanies a graphic. That is, you should tell students to obtain the descriptions and explanations in one form or the other, but not both at the same time. However, for accessibility, both forms should available.

h. Students learn new material better and can remember it longer when its presentation highlights the main points and avoids extraneous audio, graphics, and text (Clark & Mayer, 2011; Kalyuga, Chandler,

& Sweller, 1999; Kozma, 2000; Mayer, 2001; Mayer & Moreno, 2003). Called the *coherence principle*, it counsels you to present online content cleanly and simply in whatever medium you use. Get right to the point and do not elaborate more than is necessary.

i. Students learn new material better and can remember it longer when its presentation features a visible speaker using an informal, conversational style (Clark & Mayer, 2011). This personalization principle reiterates this recommendation in principle 6 about attention attractors and holders that you should use technology that shows your face. In addition to personalizing the presentation, this allows you to display enthusiasm and drama in your vocal variety, facial expressions, and gestures.

Principle 9: Multimodal Repetition

Whenever possible, give students the opportunities to process your online content in at least two or three modalities involving multiple senses. Allow them to read, hear, talk, write, see, draw, think, act, and feel new material into their system, involving as many parts of the brain in their learning as you can. If your students first read or listen to the material, follow up with having them do two of the following: discuss it, make a graphic of it, watch a video or animation of it, role-play or simulate it, or free-write about it.

Principle 10: Structured Knowledge

Structure is key to how people learn. It is what distinguishes knowledge from disparate, isolated pieces of information. Knowledge is a structured set of patterns that we have identified through careful observation, a grid that we have superimposed on a messy world to allow us to make predictions and applications (Kuhn, 1970). It encompasses useful concepts; widely accepted generalizations; well-grounded inferences; credible hypotheses; and evidence-backed theories, principles, and probabilities. Without knowledge, science and advanced technology wouldn't exist.

The human mind gravitates to structure. It is designed to seek patterns in its observations of reality and then build these patterns into explanatory structures. This means that it may make up connections to fill in the blanks in its understanding of phenomena. Some of these made-up connections stand up to scrutiny and scientific testing. For example, Charles Darwin did not observe mutations happening in nature; rather, he hypothesized their occurrence to explain species diversity. Although no one was around to watch the big bang, the theory fills in quite a few missing links in cosmology. Astronomers have never directly observed dark matter, but the theory of this undetectable phenomenon accounts for unexpected gravitational effects on galaxies and stars. Of course, not all made-up connections stand the test of time or science. Superstitions and prejudice exemplify false patterns. The belief of many people, including many students, that one's intelligence is fixed and immutable also fails under careful study.

Students lack the background knowledge to perceive the structure of our disciplines. They do not see the big picture of the patterns, generalizations, and abstractions that experts recognize so clearly, so they struggle to identify the central, core concepts and principles (Kozma, Russell, Jones, Marx, & Davis, 1996). Without having a knowledge structure in their head, they also fail to comprehend and retain new material (Bransford et al., 1999; Svinicki, 2004). The mind processes and stores information only within a big-picture structure of prior knowledge, only as a coherent, logically organized framework into which new material can fit (Ausubel, 1968; Baume & Baume, 2008; Bransford et al., 1999; Carlile & Jordan, 2005; Hanson, 2006; Svinicki, 2004; Wieman, 2007; Zull, 2002, 2011).

How long might it take for students to organize a disciplinary structure on their own? How long did it take us? Most of us needed years of specialized study and apprenticeship to discover the structure of our discipline and acquire expertise. We do not have that kind of time with our students, so we need to help them acquire the structure quickly. We must make the organization of our discipline's knowledge explicit by providing them an accurate, ready-made structure.

The best tool for displaying a big-picture structure is a graphic. Recall from principle 8 that graphics minimize cognitive load while clarifying the organization of concepts, processes, principles, and the like. They also facilitate storage and retrieval of knowledge. This is why a graphic syllabus of your course (see chapter 3) provides such a powerful learning framework. You should also furnish students with graphic representations of theories, conceptual interrelationships, and knowledge schemata and then have them develop their own graphics to clarify their understanding of the material.

Principle 11: Stories and Cases

Long before any society invented the written word, people handed down their culture and belief structure from generation to generation in the form of stories and parables. As teaching tools, stories still work well because they are easier to identify with and remember than abstract ideas. But now stories can take many forms: illustrative anecdotes, case studies, and problem-based learning problems conveyed in text, audio recordings, animations, or videos. Online courses can draw on all these story forms and media.

Principle 12: Varied Examples

Examples that represent different contexts, conditions, disciplines, and levels of abstraction enable students to induce the most robust and useful generalizations and conclusions. You can use illustrative anecdotes and assign case studies and problem-based learning problems as situational examples—the more varied they are, the better for student learning.

Principle 13: Emotions

Emotional involvement enhances students' learning and long-term retention of new material. Not only do emotions bring additional neurotransmitters into creating and reinforcing synaptic connections, but they also enhance motivation, which is so important in determining how much effort and persistence students put into their learning (Ambrose et al., 2010). Some of the attention-attracting elements listed in principle 6 double as motivators, such as instructor enthusiasm and the personal relevance of the material. In addition, motivation can involve emotions like curiosity, intrigue, fascination, wonder, surprise, compassion, humor, self-esteem, affiliation, and a sense of autonomy and control. In fact, motivation so deeply affects learning that we devote the next chapter to this topic.

Any medium can evoke emotions. Animations can be whimsical and amusing as well as instructive. Video and audio recordings can tell moving or intriguing stories as well as illustrate situations and principles. Demonstrations can yield surprising results. Readings can generate compassion or curiosity. Free writing can reinforce students' sense of autonomy and control. When choosing animations, videos, writing topics, and the like for your courses, look for those that can engage students emotionally as well as cognitively.

Principle 14: Spaced Practice

Build in activities and assignments that have students review and practice retrieving the same content at spaced intervals. Also tell students that they will perform better on tests if they space their pre-exam study sessions over several days and get a good night's sleep the night before a test instead of cramming.

Principle 15: Interleaved Practice

Interleave this spaced review and retrieval practice by having students work with prior content as they are learning new content. In other words, intersperse among the problems and exercises on new material a few problems and exercises from previously learned material. This way, students will also get practice in deciding the kind of problem they have to solve and what skills they will need.

Principle 16: Self-Regulated Learning

The process of goal-setting and planning strategies before a learning process, monitoring one's learning during it, and evaluating one's learning after it is called *self-regulated learning.* This process takes place on several dimensions: one's cognitive learning strategies (metacognition), one's emotional reactions to the material, and one's reactions to the physical environment one has chosen for learning. It requires a learner's focused self-awareness, honest introspection and self-assessment, willingness to change strategies, and acceptance of responsibility for one's learning (Pintrich, 2000; Zimmerman, 2001, 2002; Zimmerman & Schunk, 2001). You can teach your students to practice self-regulated learning by giving them assignments that engage them in doing it (Nilson, 2013). Online courses can accommodate the following activities.

As bookends for your course, you can have your students at the beginning write an informal, goal-setting essay, "How I Earned an A in This Course" (Zander & Zander, 2000), and at the end an informal, self-assessment essay, "How I Earned an A in This Course—or Not." Or you can ask them to reflect in writing on the nature of the course material at the beginning (Kraft, 2008; Suskie, 2009) and then again at the end. Or have them write take-a-stance-and-justify essays on course material at the beginning and correct and rewrite those essays, possibly as the final exam, at the end. Or administer a knowledge survey—really a survey of students' confidence in their ability to answer questions and perform tasks (Goodson, Slater, & Zubovic, 2015; Nuhfer & Knipp, 2003)—on the course learning outcomes and skills at the beginning and repeat the survey at the end. If you let students compare their before-and-after products, the last three options will make students aware of all they have learned during the course.

After content presentations in any medium, ask students to write short answers to two or three of the following questions (Chew, quoted in Lang, 2012; Kalman, 2007; Mezeske, 2009; Schell, 2012; Wirth, n.d.):

- What is the most useful or valuable thing you learned?
- What are the most important concepts or principles?
- What do you not understand clearly?
- What helped or hindered your understanding?
- What idea or fact surprised you?
- What comparisons and connections can you draw between this new material and your earlier learning in this course and other courses?

- What stands out in your mind?
- How did what you learned confirm or conflict with your prior beliefs, knowledge, or values?
- How did you react emotionally to what you read, heard, or watched?

Along with homework assignments, have students write reflections like these, appropriate to the assignment (Brown & Rose, 2008; Jensen, 2011; MacDonald, 2013; Mezeske, 2009; Rhode Island Diploma System, 2006; Suskie, 2009):

- Describe the process that you followed in doing this assignment, such as the steps you took, the strategies you chose, the problems you had, and the solutions you developed.
- What was the value of this assignment in developing your skills and expanding your knowledge for your future use?
- If you were to do this assignment again, how would you do it differently?
- What learning outcomes did this assignment help you achieve?
- What key concepts and principles did this assignment help you understand better?
- How well did you achieve your goals for this assignment?
- What advice would you give to future students in this course about this assignment? What approach should they take? How can they avoid likely problems? What skills should they work on improving?
- For every problem you did not complete correctly, describe where you went wrong (or describe the correct strategy for solving it) and resolve the problem (or a similar problem) (Zimmerman et al., 2011).

After a simulation or academic game, ask students to describe and evaluate their goals, decisions, strategies, and responses to the actions of other students.

After you return graded exams, have students reflect on and analyze their results by answering questions like these (Barkley, 2009):

- How did your actual performance compare with what you expected? How do you feel about your actual performance?
- How many hours did you study for this exam, and what study strategies did you use? Did you study long enough? How well did your study strategies work?
- Look at where you lost points. What patterns do you see in why you lost points?
- How will you prepare differently for the next exam?

While students should submit these assignments, you need grade them only pass or fail and attach some nominal number of points to passing. To pass, students have to complete the assignments (e.g., answer all the questions) and meet a minimum word requirement that you set. If you want students to delve into considerable depth, you should develop a rubric and use it to grade the assignments (Nilson, 2013).

Principle 17: The Testing Effect

Build into your course plenty of assessment opportunities, including low-stakes quizzes and exams, practice tests, and homework assignments that can tell students how much they are really learning and give them retrieval practice (Roediger & Butler, 2010). Also teach students how to most effectively read text, listen to audio recordings, and watch videos and animations. First, they should read, listen to, or watch the

assignment; then free-recall as much as they can by writing it down or reciting it aloud; and finally review the assignment to find what they forgot, missed, or recalled incorrectly. This technique, which incorporates self-testing, is much more efficient than just rereading the material, even many times (McDaniel et al., 2009; Roediger & Karpicke, 2006).

Principle 18: Comprehensive Exams

When students expect to have to recall content and perform skills again in the future, they will keep the content and skills more accessible in memory. The teaching implication is obvious: plan on giving a comprehensive final, and tell your students from the beginning that you will.

Principle 19: The Generation Effect

When students know that they will have to produce (e.g., write, design, or problem-solve) answers by free-recalling material, they will learn it more thoroughly than when they know they will only have to recognize correct answers on an objective test. Therefore, test students on the most important material using short-answer items, essay questions, and problems to solve. Ask for explanations, analyses, and evaluations. Tell students in advance what material merits short answers, essays, complete problem solutions, and the like so they will study accordingly.

Even before you test, accustom your students to generating answers to questions before, during, and after readings, podcasts, videos, animations, and exercises (Williams, 2013). Ask them the questions that foster elaborative rehearsal (see principle 7 above) about how the material relates to what they already know, what it means on a deeper level, or why it is important. Or you can ask them to free-recall descriptions, explanations, and analyses contained in the presentations or exercises. To ensure students answer these questions, have them submit their responses and grade these pass or fail.

Principle 20: Desirable Difficulties

These difficulties can help students generate multiple retrieval paths and stretch their abilities. However, avoid challenges that increase cognitive load. The following are ways to integrate desirable difficulties into student learning (Persellin & Daniels, 2014), not all of which may be under your control and oversight:

- Have students recast text material into a graphic format such as a concept map or flowchart.
- Vary the conditions and location of their practice opportunities.
- Have them transfer new knowledge to new situations.
- Have them handwrite notes on the assigned readings, podcasts, videos, and animations.
- Hold students to high standards—for example, refuse to accept or grade work that shows little effort.
- Assign especially creative, inventive, or challenging tasks to small groups.

Principle 21: Challenges to Current Mental Models

This principle connects with principle 4 about the learning effects of prior knowledge and mental models that students bring into your course. However, principle 4 focuses on the importance of overturning students' faulty mental models, while this one points out that students who seriously question their

misconceptions reap the extra learning benefits of greater curiosity, more motivated inquiry, and deeper reasoning, which are needed to restore their cognitive equilibrium. This is another example of a desirable difficulty. In other words, identifying your students' faulty mental models provides you with powerful teachable moments as you reveal the superior explanatory strength of your discipline's model with telling demonstrations, animations, videos, simulations, videos, or readings.

Principle 22: Deep Thinking and Explanation Questions

To facilitate your students' learning, model asking challenging, thought-provoking questions that require high-level critical or creative thinking; avoid simple recall and descriptive questions. Prompts that begin with *why, how,* and *what if* are promising candidates. Discussion threads, reflective assignments, and untimed quizzes present excellent opportunities because students have the time to think deeply before responding.

You also want students to ask such questions themselves, so consider assignments where students develop thought-provoking questions on a reading, video, or other content presentation. You can use some of these questions as prompts for discussion threads or short writing assignments or as quiz and exam questions. When students know you will use them in some way, they will be motivated to suggest good ones.

Principle 23: Error Correction

This principle is somewhat related to principle 21 because both highlight the benefit of error. However, this one emphasizes that any kind of error provides a rich and memorable learning experience when students have the chance to correct it (Najafi, Giovannucci, Wang, & Medina, 2014). The idea of learning by one's mistakes may not appeal to students at first because mistakes cost them points, but you can explain to them the long-term payoffs.

Principle 24: Prompt Feedback on Errors

The teaching implication of this learning principle is obvious: return graded assignments and tests as soon as you can, while students can still remember what they were thinking when they were completing the assignment or test.

Principle 25: Print Text for Reading

While the mind normally does not shift gears when faced with the same material in a different medium, it may so do if it has been trained or has trained itself to operate differently. Research has uncovered some weaknesses in e-textbooks and web-based readings as learning tools, despite their money-saving virtues. Unfortunately, people tend to read any material on a screen quickly and superficially, the same casual way they read novels on an e-reader or social media or the news on the web. But reading course material demands focused mental processing. As a result, students learn and retain less when they read an e-textbook than a print textbook (Baron, 2015; Daniel & Willingham, 2012; Daniel & Woody, 2013; Kolowich, 2014; Wästlund et al., 2005). Similarly, reading from websites leads to lower comprehension than reading from a book, especially on complex topics and for students with less working memory capacity (Mangen et al., 2012; Sanchez & Wiley, 2009). One survey-based study that reported comparable course performance between students who selected the print textbook and those who chose the electronic version also

found that the latter tended to print out their text to mark up and take notes on it (Rockinson-Szapkiw, Courduff, Carker, & Bennett, 2013).

The design of electronic materials can also inhibit storage and retrieval (Rosenfield, Jahan, Nuñez, & Chan, 2015). These materials offer fewer, if any, of the valuable, effortless retrieval cues that print textbooks do. Visual and tactile information such as page layouts, page location of content, paper texture, colors, and font features flow automatically into long-term memory when students are reading a book, especially one with varied page layouts. This information helps students retrieve text material more easily (Mangen et al., 2012; R. Pak, personal communication with L. Nilson, May 13, December 12, 2013).

In most research, students report that they cannot learn material as quickly and efficiently from an e-textbook as they can from a print version. They admit to wandering off into digital distractions that are just a few clicks away, while their peers reading a book are less tempted and more focused (Daniel & Willingham, 2012; Daniel & Woody, 2013). These distractions include text-embedded hyperlinks, which can be enrichening, but it turns out that reading is a linear mental process (Tanner, 2014; Zhang et al., 2012). Therefore, when you create your own online materials, avoid complex interfaces.

Publishers, however, can produce e-textbooks and web-based materials more quickly than print materials, so the information may be more up-to-date. In addition, well-designed materials provide opportunities for multimodal learning. In astronomy, some e-textbooks offer helpful and engaging visuals and animations. In music, e-materials may include audio samples of different types of music. Embedded videos and instructor annotations can also aid learning (Gu, Wu, & Xu, 2015). In one study conducted in Thailand, third-year professional students in medicine, a visually intensive discipline, learned just as much from the electronic version of their textbook as they did from the print version (Samrejrongroj, Boonsiri, Thunyaharn, & Sangarun, 2014). Therefore, even if online materials are not as good for reading as print, they can be valuable study aids when their content and exercises are high quality and the visual and audio enhancements complement the subject matter.

You might give students a choice between the print textbook and e-textbook when both are available with the same content. Show the e-book users how to highlight text and make annotations to augment their study strategies (Denoyelles, Raible, & Seilhamer, 2015).

When you choose online instructional materials, consider these all-important features:

- Overall organization
- Logical sequencing of topics
- Readability in language and layout
- Consistency of headings and subheadings
- Chunking and blocking of material
- Existence of introductions and summaries
- Utility of visuals and animations
- Attractiveness of the color treatments
- Compatibility with a screen reader so that students can listen to rather than read the text

In addition, look for call-out boxes or font styles that draw attention to the concepts you deem important for your learning outcomes rather than trivial bits of information (Florida Department of Education, 2008). If you are willing to customize online materials with your own annotations, choose an e-textbook that allows this option.

When creating your own materials, maximize online readability by selecting these two text features (Geraci, 2006):

- A sans serif font (like Arial or Verdana) because it lessens eyestrain and increases retention (a serif font, like Times Roman, is better for paper-based reading)
- Nonjustified paragraphs because they make words easier to read and increase retention

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Cognitive psychology provides valuable insights into how people learn and how we can best teach students in online as well as classroom-based courses. The implications of this discipline's findings span course design, content organization and presentation, teaching strategies, assessment methods, social interaction, and feedback on assignments and exams. If we want to make learning as trouble free and gratifying as possible for our students and facilitate their success, we ignore this research at our own and their peril.

This chapter does not address one final principle: students learn new material better and can remember it longer when they get adequate sleep and exercise (Doyle & Zakrajsek, 2013). Unfortunately, these important factors are beyond your control. All that you can do is educate students about the considerable effects of sleep and exercise.

Reflections

For Instructors

- What principles of learning can you apply in the course you are designing?
- How do you want to use online technology to implement these principles?
- What procedures and processes are critical to learn in your course? How will you present them to students?
- What active learning strategies can you use in your course?
- How can you provide targeted feedback for the practice activities and assignments in your course?
- How can you reassure students that they will be learning in a supportive and welcoming environment?
- What faulty mental models do your students bring into your course, and how can you convince your students of the validity of your discipline's models?
- How can you personalize your course to share your passion for what you are teaching and ensure the personal relevance of the content to your students?
- What forms of elaborative rehearsal of new content can you incorporate to help students make connections to valid prior knowledge and consider the importance of the content?
- What material in your course may increase your students' cognitive load? How can you reduce that load?
- How can you ensure that your students review new material at least two or three times in different modalities?
- What can you do to help students see the big picture of your course content?
- What examples, stories, and cases can you draw on to advance students' learning? How can you ensure they are varied? Where can you best place them in your course?

- How can you add emotions to your content presentations and student activities? Do any of your examples, stories, and cases evoke emotions? How will you know what your students find challenging?
- What opportunities for review and practice can you provide? How can you space them to maximize learning?
- How will you incorporate self-regulated learning assignments and activities into your course?
- How can you add more chances to test your students or for them to test themselves?
- How can you teach your students to ask challenging, thought-provoking questions—those that begin with *why, how,* and *what if* and evoke high-level critical or creative thinking?
- What essay-type and short-answer questions can you inject into your discussion forums, chats, and tests?
- How can you add desirable difficulties into your course materials and learning activities without increasing cognitive load?
- How will you build in opportunities for students to correct and learn from their errors?
- How will you select and develop online materials for your students to read and study?
- If considering an e-textbook, make sure you find answers to the following questions:
  - Do students have the choice to buy a print-based edition with the same content?
  - Can students effortlessly download and print sections of the e-textbook?
  - What is the functionality for "turning" the pages—that is, moving from one to the next without getting lost or stuck? (Look for page-like rather than scrolling presentation.)
  - How easy is it to make annotations and access embedded multimedia within the e-textbook?
  - How well does the e-textbook work with a screen reader so that a student can choose to listen rather than read the text information?

For Instructional Designers

- How can you apply the principles of learning in helping the instructor design and develop the course?
- How can you use the tools in the LMS to apply those principles?

For Administrators

- How can you support your online faculty and instructional designers in applying these principles of learning in online courses?
- What kind of peer-sharing or peer-review process can encourage dialogue or review and feedback on ways to improve the integration of these principles?

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