CHAPTER

10 Technological Contexts for Cognitive Growth

This chapter is about technologies for learning and teaching. Simply put, a technology is any device or system that we humans use to accomplish our goals. The wheel, an oar, an abacus, a hammer, a toothpick, and a TV set are various examples. In education, some technologies have been with us for hundreds and even thousands of years—items to write with (e.g., a stylus, pen, pencil, and chalk), record ideas (e.g., papyrus, paper, and chalkboards), and preserve and share information in an organized way (e.g., scrolls and books).

When educators refer to technology, however, they almost always are referring to a cluster of continuously evolving electronic hardware (e.g., computers, laptops, handheld devices, MP3 and DVD players), communication networks linking these devices (e.g., wireless networks, cable TV, the Internet), and associated software (e.g., word processing, presentation programs, apps, simulations, games, Web browsers). In this chapter, we focus on these electronic technologies and examine the implications of cognitive psychology for their design and use.

Educators increasingly are aware of technology's potential for changing how learning and teaching take place. Even though education continues to lag behind other segments of society in using technology, having a relatively low level of classroom use compared to its integral part of our daily lives as we bank, shop, search for information and use our cell phones in a growing number of ways, there is hope that technology can improve, and even revolutionize, how students learn and teachers teach.

Our modern era is not the first in which there have been hopes about technology's promise. When movies and television first appeared predictions were made that they would replace most, if not all, classroom instruction. That has not happened. But today's versatile technologies do seem to warrant optimism. With technology an obvious feature in all of our lives and playing an increasing role in schools, where students have access to course-related e-mail communication and Web-based resources such as course syllabi, assignments, reading materials, and practice exams, there is growing interest in how it might be best used. Should students work with technology alone or collaboratively? Can technology facilitate classroom discussions and provide practice opportunities? Can it help promote educational equity? Can online education be effective? Should we spend school resources on handheld devices or are computer labs still a good investment?

The point of this chapter is not to recommend specific new instructional technologies shown by research to produce gains in learning outcomes. There are none. One of the most consistent findings when the educational technology research literature is carefully reviewed is that there are few if any improvements in learning outcomes specifically attributable to the technology alone. That is, when technologies such as online presentation and discussion of teaching case studies by teacher education students are compared with traditional approaches (e.g., the same students reading and discussing teaching case studies in the classroom), there seldom are learning benefits attributable to the technology itself (e.g., see Clark, 1994, 2001, 2003; Salomon, 1984).

What instructional technology research *does* show is that learning is influenced primarily by good instructional methods that *take advantage of what technologies have to offer*. That is, technology *per se* is not what motivates learners and produces learning, but how that technology is used. We will focus on technology in the hands of skilled teachers, teachers who understand cognitive and motivational principles and can turn them into effective instruction. When such teachers guide technology use, what can it do for student learning and cognitive growth?

We begin with an overview of some of the many technology-based resources available to students. Which ones are best suited to different kinds of learning goals? Simultaneously we look at several key cognitive skills and strategies students need to use technology effectively. Taking full advantage of technology's potential requires that students have a repertoire of knowledge, strategies, and beliefs. We highlight several of these that we see as especially important.

In the following four sections we describe some of the theory and research guiding today's instructional technology development. What kinds of cognitive and motivational theories currently inform choices about instructional technology design and use? The first of the four sections describes *cognitive load theory* and multimedia design. Cognitive load theory, which we introduced in Chapter 2, has become a focal point for thinking about instructional multimedia. We present principles based on this theory that will help you make informed judgments about whether media are well designed. The second of our theory sections summarizes the *Four-Component Instructional Design (4C/ID) model*, which provides a blueprint for how technology can be used to develop complex skills. In the third section we explore technology's potential for *scaffolding metacognition and self-regulated learning*. Here we describe how technology-supported learning environments can be used to coach and support learners in becoming more strategic, persistent, and reflective. The fourth section analyzes educational technology's uses from the standpoint of *social cognitive theory*, focusing on computer-supported collaborative learning (CSCL, Schellens & Valcke, 2005; Stahl, Koschmann, & Suthers, 2006), in which technology serves as a hub for learning communities. We conclude our chapter by exploring the growing ties between technology and assessment and the general implications of technology-based approaches for education.

How Can Students Use Technologies?

Technology itself seldom is the driving force behind learning, but it obviously can amplify and extend students' educational experiences. When we look at computer- and Internet-related technologies, we can see many ways they can be used in education. Software is readily available for creating and sharing Web-based resources such as graphics, diagrams, and videos, while wireless classrooms make it feasible to link class members' laptops or smartphones. Table 10.1 presents several ways that students can use educational technology to enhance their educational experience, while Table 10.2 presents key cognitive skills needed to take advantage of them.

The category listed first in Table 10.1—students *receiving information* via technology—is not a new one. It has a history dating back to movies and television and even before. Many teachers now use software such as *PowerPoint,* for example, to present information. This software typically has a number of capabilities for enhancing presentations, such as the ability to use varied type fonts and backgrounds and include features such as clip art, pictures, animations, and sound. These features can make information more attractive and interesting but, if used ineffectively, can distract learners and lead to loss of comprehension.

The second category of technology use, however, has developed more recently. With widening Internet access in U.S. schools and classrooms, technology has opened a significant resource for student learning—*access to information and ways to find it.* Web browsers available on computers and phones link to the Internet, and search engines allow students to find information easily and quickly. In contrast to the problem of lack of information, which many schools and students still face with shrinking libraries and scarce textbooks, technology is creating ironic new challenges—information overload coupled with access to information of dubious quality. As shown in Table 10.2, students need to learn systematic methods of searching for information and recognizing differences in its quality; without these skills, student searches can be derailed by momentary factors (e.g., unusual links turned up by search engines or a succession of interesting-looking links) and result in erroneous or biased information (e.g., from personal Web sites or sites run by unmonitored groups).

Increasingly, technology can help students *organize and present information.* Programs such as *Inspiration* allow students to compile information in formats ranging from semantic maps to outlines. These then can serve as multimedia storyboards or frameworks for essays or stories. To actually present information, many choices are available, including word processing (e.g., Word), desktop publishing (e.g., PageMaker, InDesign), multimedia development (e.g., Flash, Director), and Web design programs (e.g., Dreamweaver). What students produce—papers, multimedia presentations, or Web pages—can range from simple summaries to highly complex productions involving gathering, organizing, refining, and presenting information. The best projects can call on virtually all of a student's cognitive, self-regulatory, and motivational resources.

As students increasingly become involved in complex projects that start with information gathering and lead to information transformation and presentation, teachers should consider the many challenges students will face and devise strategies to help them be successful. Self-regulation skills are critical, as students need to monitor their progress and adjust strategies in order to continue moving ahead. Many will need assistance not only with becoming skillful in using the technology (i.e., developing procedural skills) but also in developing a mastery orientation toward both learning to use the technology itself and completing complex

TABLE 10.1 Selected Student Uses of Technology

Use	Examples of Available Technologies	Examples of Student Use
1. Receive information	• Presentation packages (e.g., PowerPoint)	• Ninth-grade biology students view multimedia presentation that includes video of cell reproduction
2. Search for and find information	• Web browsers (e.g., Firefox, Internet Explorer) • Search engines (e.g., Google, Yahoo!)	• Fourth graders identify keywords to search for information on habitats of foxes, coyotes, and dingos • Eleventh graders find information about the Lewis and Clark expedition on the National Geographic Web site
3. Organize and present information	• Organizing, outlining programs (e.g., Inspiration) • Presentation packages • HTML editors, authoring packages (e.g., Dreamweaver, FrontPage)	• A team of sixth-grade students creates a semantic map to guide their writing on their paper "Life in the Rain Forest" • Teacher education students develop a several-part "philosophy of teaching" that is posted on their class Web site
4. Explore simulated environments	• Simulation games, visualization tools (e.g., SimCity Societies, Geometer's Sketchpad)	• High schoolers use Sketchpad to model a Ferris wheel's motion and graphing activities to learn trigonometry concepts
5. Participate in authentic learning environments	• Communication software (e.g., Thunderbird, Outlook, Gmail) • Databases (e.g., Access, FileMaker Pro) and Web sites • Statistical packages (e.g., SAS, SPSS)	• High school students in several states gather water quality and climate data from their area, send it via the Internet into a database, make hypotheses about trends in data, and compare findings with each other
6. Communicate and collaborate with other students	• Communication and collaboration software (e.g., Skype, iChat, Adobe Connect Pro)	• Graduate students located in several countries taking a school administration distance learning course participate in threaded discussions, work groups, and projects to complete course requirements
7. Practice skills and receive feedback on progress	• DVD or Internet-based programs aimed at skill development • Course management software (e.g., Blackboard, Moodle) for supporting online learning	• First graders practice matching letters to letter sounds using an animated computer program • College students in psychology take several practice quizzes sampling unit objectives, use results to gauge their progress and decide when to take unit mastery tests
8. Use technologies for cognitive support and extending abilities	• Screen readers (e.g., JAWS) that convert on-screen text into speech • Voice recognition systems (e.g., Kurzweil Voice, Dragon Naturally Speaking) allowing computer users to dictate text directly • Word prediction programs (e.g., Co:Writer) that offer likely words after beginning letters are typed	• Visually impaired graduate student explores the Internet from a Windows environment • Eighth grader with poor writing skills dictates words and punctuation into a word processing system • Learning disabled high school student uses word prediction program to find appropriate words and reduce misspellings in an assigned paper

TABLE 10.2 Some Key Cognitive Skills Students Need to Use Technologies Effectively

Key Student Skill	Potential Pitfalls for Students in Using Technology	Strategies Teachers Can Use
1. Locating and judging information	• Following links randomly • Attending to seductive details • Getting "lost" in information searches • Being overwhelmed by too much information • Selecting erroneous or low quality information	• Limit searches to a few questions and limited number of sites (e.g., WebQuest) • Explicitly teach search and summarization strategies • Stress careful preparation for searching • Teach students to self-monitor search and summarize success
2. Communicating effectively using technology	• Lack of effective writing skills • Lack of media design skills • Not understanding purposes of communication • Uncertainty about roles in learning communities • Receiving negative feedback on communication attempts	• Arrange authentic communication opportunities • Explicitly teach writing and media design strategies • Encourage students to use graphic and other organizers to prepare for communication • Create safe environment for online communication
3. Using self-monitoring and self-regulation skills when using technology	• Not understanding overall goals for learning • Failing to monitor progress toward goals • Producing low quality products (e.g., writing, multimedia presentations) • Participating erratically in activities, projects	• Help students select interesting, intrinsically motivating projects • Help students set goals and subgoals for projects • Teach self-regulation skills tied to technology use, including monitoring progress • Create opportunities for students to share products and receive feedback • Provide frequent feedback to students on progress toward goals
4. Proceduralizing knowledge	• Not practicing skills sufficiently • Lack of just-in-time information • Lack of awareness of skills' role in larger tasks	• Give students repeated practice opportunities to proceduralize program knowledge • Engage students in discussions about skills needed to achieve goals • Help students link procedural skills to conceptual understanding
5. Contextualizing knowledge	• Failing to comprehend virtual structures (e.g., organization of word processing programs, browsers, operating systems) • Not applying already-learned skills and knowledge to solving new problems	• Complement development of procedural skills with conceptual instruction • Provide graphic organizers to aid students in linking features
6. Adopting a mastery orientation toward technology-based learning	• Not using alternative strategies when difficulties are encountered • Losing motivation to continue with projects	• Help students set and monitor progress toward intermediate and long-term goals • Remind students of utility of learning • Give frequent feedback on students' progress toward goals

projects utilizing several different kinds of technology (e.g., word processing, multimedia development, and Web authoring programs).

Many educators also recognize technology's growing potential for giving students opportunities to learn in new ways. Students can use *simulated environments* and *visualization tools* to create and visualize things as diverse as mathematical functions, using Geometer's Sketchpad, and a society's workings, using SimCity Societies. Because they require powerful computing, technology-based simulations once were largely confined to higher-end applications (e.g., in film studios, architectural firms). This situation has changed rapidly with development of simulations on personal computers and handheld devices offering high realism and responsiveness. Simulations and games have the potential to offer routes to learning activities students find intrinsically motivating and worthwhile in their own right.

Mirroring our culture's rapidly expanding use of wireless devices and the Internet to communicate, educational *uses of technology for communication and collaboration* are growing. Many students and teachers now routinely interact by e-mail and texting; class Web sites and listservs provide class members with easy access to information, ability to share it with class members, and chances to work together. Success in communication does not happen accidentally, of course; it requires worthwhile issues to communicate about and hinges on students' writing and media skills. While such skills to some extent develop just by working with communication technologies (e.g., sending e-mails and contributing to a discussion on a class discussion board), they often require coaching, feedback, and extensive practice to develop the proceduralized knowledge needed for skilled performance.

Technologies can make *opportunities for practice and feedback* available. Many elementary students use at least some computer-based technology for skill development. While instructional quality can vary tremendously, a host of DVD-based programs, for instance, are available for developing elementary students' literacy (e.g., a program for beginning readers includes practice in picking out rhyming words) and math skills (e.g., a program for third and fourth graders presents practice sets of addition or subtraction problems). Similarly, students in high school and college classrooms now can take repeated Web-based practice quizzes sampling unit content. The feedback they receive allows them to judge how close they are to mastery.

Finally, a cluster of technology-related products and equipment, collectively called *assistive technology,* is now available to support and extend the abilities of learners with disabilities. Assistive technologies continue to multiply, stimulated by developments in fields as disparate as computer hardware and software, robotics, and speech recognition. Some assistive technologies, such as environmental control devices and robots, are primarily aimed at helping individuals who have physical disabilities. Others, more directly related to the cognitive focus of this text, provide significant assistance to individuals with disabilities that interfere with performance of school-related tasks such as reading, writing, spelling, and math.

For example, intelligent word prediction programs for phones, word processors, and e-mail now are available. Users need only to begin to spell a word and likely possibilities are displayed. Sophisticated programs also are available to aid and extend students' cognitive abilities, including systems that read scanned text aloud, browsers that translate Web content into speech, and voice recognition systems that allow users to dictate text directly into computers.

In summary, instructional technology has the potential to provide students with many learning opportunities and extend their cognitive functioning. Some are not new—for example, using technology to receive information from a presentation. Others, however, are opening up entirely new avenues to learning resources and have potential for supporting active, meaningful collaborative learning. Technology uses range from gathering, organizing, and presenting information to interacting with others on group projects. Still other uses are targeted at learners with disabilities, providing technological supports ranging from speech recognition to text-to-speech conversion. Using technology effectively requires many different student competencies (see Table 10.2) ranging from knowing how to search for information to having a mastery orientation that will carry them through the challenges of using technology in complex, long-term projects. To help us think more specifically about productive uses of technology and how students can use it, we now turn to the theory and research on technology, cognition, and education. We begin with cognitive load theory.

Cognitive Load Theory and Multimedia Design

Cognitive load theory, proposed by John Sweller and his associates (Sweller, 1999; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005), focuses on the role of working memory in instructional design. Cognitive load theory increasingly has been applied to the design of educational multimedia, such as computer-based instructional programs and multimedia (Clark, 2003; Mayer & Moreno, 2002; van Merriënboer & Ayres, 2005; van Merriënboer & Sweller, 2005). From a cognitive load perspective, meaningful learning depends on active cognitive processing in learners' working memory. The difficulty is that working memory can only process a few units of information at any given time (see Chapter 2). If learners encounter too many elements in a multimedia presentation—for example, one combining animations, graphics, sounds, printed text, and narrated text—working memory can be overwhelmed. The result of excessive cognitive load, or too many pieces of information being juggled in working memory, is decreased processing efficiency and, at worst, a collapse of the learning process.

Understanding the two types of cognitive load, intrinsic cognitive load and extraneous cognitive load, can help us analyze whether given multimedia presentations are likely to create issues of cognitive load. **Intrinsic cognitive load,** according to Sweller, is a characteristic of the materials themselves in relation to the learner's expertise. Any content being learned creates intrinsic cognitive load in working memory based on its difficulty and complexity. For example, a multimedia presentation for ninth graders on biodiversity will generate a certain amount of intrinsic cognitive load associated with the complexity of the topic of biodiversity and associated concepts. Because it relates primarily to the content itself, intrinsic cognitive load typically cannot be altered. **Extraneous cognitive load,** on the other hand, is affected by the instructional design, such as how a multimedia presentation is organized and the kinds of information included (e.g., clip art, animations, and text). If a presentation contains multiple information sources such as diagrams and texts that need to be mentally integrated, extraneous cognitive load will be generated. In contrast to intrinsic cognitive load, extraneous cognitive load is controllable—better instructional designs create less of it, less effective designs create more.

Intrinsic and extraneous cognitive load are additive; if both are high, working memory capacity can be overwhelmed. Because only extraneous cognitive load is under the control of instructional designers, who can change *how* content is presented but typically cannot change the content itself, the challenge is to design instruction that reduces extraneous cognitive load. To meet this challenge, Sweller and his colleagues have focused on two resources: (1) long-term memory (LTM), with its nearly unlimited capacity and processes of schema formation, and (2) the unique nature of working memory.

First, because LTM has great capacity and many learners possess domain-related knowledge schemas (e.g., a biology student with prior knowledge of cell division processes and a music history student with knowledge about Baroque and Classical composers), multiple elements of information often can be chunked into a single element (see Chapter 3). Chunking reduces the burden on working memory for these learners (Kalyuga, Chandler, & Sweller, 2000). Also, the more automatized schemata are, the more working memory capacity is available for comprehension and problem solving. Thus, multimedia designers (e.g., Merrill, 2000; van Merriënboer & Kirschner, 2007) suggest features targeted at encouraging schema automation.

One approach has been to present *goal-free problems,* in which students practice repeatedly on problem subgoals to attain automaticity, such as calculating many different angles in a geometry program until this skill is very well-learned, *before* they encounter the more complex overall problem-solving task of proving a geometry theorem. Expressed in the terms introduced in Chapter 8, cognitive load is reduced when part of the instruction allows students to use a *goal-free* as opposed to a *mean–ends* strategy. Many times, in trying to solve problems learners are asked to hold and process too much simultaneously in working memory—the current problem state, the goal state, operators to reduce differences, plus a set of subgoals. While Sweller and others (e.g., van Merriënboer, Clark, & de Croock, 2002) caution against overuse, a goal-free approach can be effective because it requires remembering only a specific subgoal and operators applying to it, reducing cognitive load.

A second major way of reducing working memory in multimedia designs is to take advantage of working memory's unique nature. As discussed in Chapter 2, working memory involves two separate channels (Baddeley, 2007; Paivio, 1986a): the visual channel (the *visuospatial sketchpad*) that takes input from the eyes and makes a pictorial representation; and the auditory channel (the *phonological loop*), which produces an auditory representation. As described there, awareness of working memory's visual and auditory channels is important in designing multimedia that avoid cognitive overload problems.

In a series of studies, Mayer and his associates (see Mayer & Moreno, 2002) compared learning outcomes for students receiving computer-presented materials consisting of narration alone to conditions in which narration was paired with an animation. As expected, students having both narration and animation learned better. In further studies, Mayer and his group compared narration and animation presented at the same time (*simultaneous group*) with successive presentation of the same information (*successive group*). In each of the studies (see Mayer & Moreno, 2002), students learned better from simultaneous presentations than from successive presentations. In Mayer and Moreno's view, these results occurred because simultaneous presentation aided learners in making connections between verbal and visual representations in working memory. In these studies, students showed few effects of excessive cognitive load.

In later studies, however, Mayer and his colleagues began to experiment with multimedia conditions calculated to test the capacity of verbal and visual working memory channels. In one set of studies, Mayer's group examined a common practice of multimedia designers—creating highly active screen designs in multimedia presentations by adding interesting explanations or sound effects. Many designers believe that such features make learning more interesting and motivating. What Mayer and his associates found, however, were negative learning outcomes. In an instructional multimedia sequence about lightning, for instance, adding interesting facts (people in swimming pools are sitting ducks!) and sounds to illustrate the steps in lightning formation (e.g., gentle wind, static, and thunder) actually *reduced* learners' problem-solving transfer, as did including instrumental background music. Mayer attributed these results to cognitive load issues. Consistent with predictions from cognitive load theory and contrary to common belief, students learned more deeply when multimedia did *not* include such words and sounds.

A further interesting test of cognitive load theory in multimedia design involved pairing either on-screen or narrated text presentations with animations to test the so-called *modality* (e.g., Mayer & Moreno, 1998; Moreno & Mayer, 1999) or *split-attention* effect (Mousavi, Low, & Sweller, 1995). Cognitive load theory predicts that when animations are used, adding on-screen text can overload working memory because both text and animation must be processed *in the visual channel.* In contrast, when animation is paired with *narrated* text, having the text presented in spoken form should reduce load in the visual channel and increase the chances of deeper cognitive processing. This, in fact, is what these researchers found.

Another common belief among many multimedia designers is that providing multiple sources of the same information (e.g., animation and on-screen text plus narration of the on-screen text) creates useful *redundancy.* From this perspective redundancy should improve learning because learners can choose to learn in their preferred style (e.g., some learn better from animations, others from reading or listening). Generally, it was found that redundancy does not promote deeper learning, but actually diminishes it (e.g., Craig, Gholson, & Driscoll, 2002; Mayer, Heiser, & Lonn, 2001).

In summarizing this research, Mayer and Moreno (2002, 2003; Moreno, 2005) have proposed several principles for guiding multimedia designs that take cognitive load demands into account. Among them is the principle of *contiguity,* which refers to presenting related information simultaneously rather than successively. For instance, when related verbal and visual information (e.g., a diagram and explanatory text) are encountered simultaneously in a multimedia presentation rather than successively, learning and problem-solving transfer will be improved. A second principle is *coherence,* based on research (e.g., Moreno & Mayer, 2000) showing better learning when learners don't have to process extra words, sounds, and pictures. Paralleling cognitively based work in Web design, where "cleaner" designs (e.g., fewer features, minimal words on a page) are seen to be better at guiding attention and memory, the more effective presentations are those that are not embellished and where focus is kept on goal-relevant content.

A third principle, *modality,* refers to taking advantage of working memory's structure by providing information that can be processed through visual *and* verbal modes, such as presenting animations with narrated text. Closely related are the potentially negative effects of *redundancy* in multimedia instruction. Adding redundant information to concise, but effective, explanations usually is unhelpful, especially when redundant information must be processed in the same channel as the primary information. For example, in multimedia materials using animations (processed *visually*), adding on-screen text (also processed *visually*) that duplicates narrated text (processed *auditorily*) is likely to create extraneous cognitive load by placing too many demands on visual working memory.

In summary, cognitive load theory provides much food for thought for those designing or selecting instructional multimedia. Working memory needs to be used effectively if students are to achieve deeper learning such as comprehending scientific principles and transferring problem-solving skills. Learners need to actively process, organize, and link multimedia content in working memory, but we also need to ensure that multimedia learning activities do not overload it. Two ways of avoiding this are drawing on learners' schemas from LTM and helping them automate new ones. Others are connecting information to permit simultaneous processing and not presenting too much information in a single channel. These strategies will help decrease extraneous cognitive load and increase students' chances of success.

The Four-Component Instructional Design (4C/ID) Model and Complex Skill Development

In the previous section, we discussed cognitive load theory and its uses for matching multimedia materials to the characteristics of working memory. But multimedia designers often must also grapple with larger-scale issues of organizing and sequencing whole instructional programs, particularly if they are designing systems for complex cognitive skill development (see, for example, van Merriënboer & Kirschner, 2007). Complex cognitive skills include those that experts perform, such as doctors making a medical diagnosis, architects designing a building, or pilots responding to emergencies.

van Merriënboer's **Four-Component Instructional Design (4C/ID) model** (van Merriënboer, 1997; van Merriënboer et al., 2002; van Merriënboer & Kirschner, 2007), based on work in cognitive psychology and cognitive science, was formulated to guide this kind of complex instructional design. The 4C/ID model rests on the basic premise that complex skills are learned by performing them, so instructional multimedia design based on the 4C/ID model focuses on giving *practice opportunities* rather than just presenting information. The system is designed so that learners acquire skills through practice, with information made available as needed to support skill acquisition.

The first of the 4C/ID model's four components is the *learning task*. As van Merriënboer et al. (2002) point out, complex learning always involves achieving *integrated* sets of learning goals, not learning separate skills in isolation. The 4C/ID model promotes use of learning tasks that are whole, authentic, and concrete. An online course for developing expertise in photography might be organized around the task of creating a black-and-white photo essay, an authentic task. It also would consist of subprograms teaching the required skills and associated knowledge needed to perform the task, such as skills and concepts related to composition, focus and depth of field, lighting, film developing, and making prints.

Learners participating in technology-based instruction based on the 4C/ID model typically would begin work on a cluster of relatively simple, but meaningful tasks called *task classes*. They then progress toward more complex ones. Complexity is determined by the number of skills involved in task classes, how the tasks classes relate to each other, and the amount of knowledge needed to perform them. The lowest level task classes—where instruction of novices would begin—are the simplest versions of whole tasks that experts would encounter in the real world. For example, medical students being asked to make a diagnosis where the symptoms are fairly obvious and the probability of correct diagnosis high. The top-level task classes correspond to the most complex problems that experts would encounter in the real world. High levels of support are given for learning tasks early in a task class; this support would include such techniques as *worked-out examples*, which have been shown to reduce cognitive load (Sweller et al., 1998), or an expert performing a task while simultaneously doing a think-aloud explaining the problem-solving processes behind task performance. By the time learners reach the final learning task, support has been faded out. This pattern of scaffolding and fading support is repeated for each subsequent task class.

One reason for fading support in across task sequences in technology-based training is the so-called **expertise reversal effect** (Kalyuga, Ayres, Chandler, & Sweller, 2003; van Merriënboer & Sweller, 2005). Simply put, supports (e.g., coaching) and instructional methods (e.g., small, incremental steps) that work well for novices can actually have negative effects for more advanced learners. For instance, worked examples, which generally are useful for novices, can become redundant for advanced learners and actually increase cognitive load. Noting the existence of the expertise reversal effect in use of worked examples, Renkl and Atkinson (2003) have recommended a *fading guidance* approach, in which, say, multiple examples might be provided and self-explanations heavily prompted early on in training. These then would gradually yield to activities more suitable for advanced learners, such as imagining solution steps and actual problem solving.

The second and third components of the 4C/ID model are *supportive information* and *just-in-time (JIT) information*. These two types of information play different roles in developing complex skills using technology. To understand these roles, we need to revisit a distinction made earlier in our text between controlled and automatic information processing (see Chapter 2). As you recall, *controlled processes* are effortful, error-prone, easily overloaded, and require focused attention. They basically are equivalent to *schemata* (see Chapter 3). In contrast, *automatic processes* correspond to *procedures* (see Chapter 3); they occur with little or no effort, are data-driven, and require little or no conscious attention. In the 4C/ID framework, the schema-like controlled processes are called **nonrecurrent skills** (van Merriënboer & Kirschner, 2007; see also Chapter 3), and the procedure-like automatic processes are called **recurrent skills.**

Nonrecurrent and recurrent skills together comprise complex cognitive skills; that is, complex cognition consists of both controlled and automatic processes. From the standpoint of the 4C/ID model, the primary challenge in developing complex cognition is to refine and automate *nonrecurrent skills*. Learners need them because schemata represent the powerful generalized knowledge required to solve new, unfamiliar problems (van Merriënboer & Kirschner, 2007). But complex skills also depend on automatically executing production-like recurrent skills. The main instructional goal for these is to automate them as much and as rapidly as possible.

Returning to the second and third components of 4C/ID model, instructional technology systems need to provide *supportive information* to help learners master the *nonrecurrent* aspects of complex cognitive tasks. Supportive information provides a bridge between learners' prior knowledge and the learning tasks. In our example of an online course intended to develop photography expertise, supportive information early in instruction might include analogies between the camera and the eye; between a photo essay and a story; or computer-presented illustrations of high and low-contrast scenes, showing changes in how clearly objects can be viewed against varying backgrounds. Similarly, in a computer-based system for developing novice physicians' diagnostic skills, supportive information might include a computer-presented "guided tour" highlighting key dimensions of a hypothetical patient's lab work and symptoms, or a video clip of an experienced physician talking her way through a diagnosis.

The goal of supportive information is to help learners acquire the kinds of flexible schemata needed to cope with the varied problems of real life. Because schemata are formed and refined through a process of induction, the best route to nonrecurrent skill development is experience with a series of authentic learning tasks. According to van Merriënboer and Kirschner (2007), a series of progressively more complex problems, coupled with supportive information and learner reflection, is likely to achieve this goal.

In contrast to supportive information, *JIT information* is aimed at the *recurrent* aspects of complex skills. JIT information promotes recurrent skill automation. Recall that recurrent skills are performed almost identically in many different problem situations and that automaticity depends heavily on consistent, repetitive practice. JIT information gives learners the step-by-step guidance required to perform recurrent skills and, as the name implies, is provided as needed. It then is quickly faded. For our medical students, for example, JIT information might include specific prompts on how to use a stethoscope to listen for and recognize certain clinical symptoms or to efficiently gather basic clinical data, such as heart rate, blood pressure, and respiration—all recurrent skills. The goal is to make these basic, but critical, skills as automatic as possible as soon as possible, freeing cognitive resources for the nonrecurrent, problem-solving dimensions of medical diagnosis.

The fourth and final component of the 4C/ID model is *part-task practice*. Although computer-based instructional systems can develop both nonrecurrent and recurrent skills, we know that a great deal of practice is needed to achieve automaticity. Experienced photojournalists, for instance, can respond very rapidly to new and changing conditions without attending consciously to subskills (e.g., without thinking about framing shots, depth of field, and lighting). Similarly, we want medical personnel to concentrate on diagnostic problem solving leading to treatment, not thinking about how to perform basic skills.

As described in Chapter 8, expertise is ordinarily a slow-developing process that depends on extended practice to automatize the productions that directly control behavior. Part-task practice is a way of automatizing procedural knowledge more rapidly, while circumventing some of the cognitive load problems resulting when learners try to develop skills while simultaneously trying to solve a problem. In our example of the online photography course, novices might take part in a simulation of the steps involved in making a print, practicing the steps repeatedly. Their practice would be supported by appropriate JIT information until automaticity had been achieved. Medical students might practice listening to heartbeats and respiration sounds using a simulation where they could vary stethoscope placements until they were able to gather information quickly and without error.

van Merriënboer and his associates do not recommend that instructional sequences contain large amount of part-task practice but argue that some part-task practice can help reduce task complexity. If part-task practice is used, they advise relatively short and spaced periods of it intermixed with work on complex, authentic tasks. This pattern provides both the opportunity to practice subskills and relate them to the overall task (van Merriënboer & Kirschner, 2007).

Summary of the 4C/ID Model

The 4C/ID model, which is based on research on cognitive learning and expertise, provides a framework for designing technology systems for developing complex skills. According to the model, learners' primary experiences should be with realistic and increasingly more authentic tasks, such as projects, cases, and scenarios. Instruction should focus on practice, not information giving. The primary goal of training is schema construction and refinement, which are developed by working on varied, authentic tasks. At the same time, training systems need to develop the automated skills essential to any complex cognitive activity. Information provided to the learner must be tailored to the kind of learning taking place. Supportive information, such as coaching and modeling, aids in schema development, while JIT information, such as online help and pop-up menus, promotes automaticity. Research continues on such 4C/ID-related topics as the timing of information presentation, presentation modalities, and optimizing step sizes (see van Merriënboer et al., 2002; van Merriënboer & Kirschner, 2007).

Technology Supports for Metacognitive Development

As educational technologies become more sophisticated, there is increased interest among motivational and cognitive scientists in ways computers can be used to advance students' metacognitive and self-regulatory processes (Azevedo, 2005; Berthold, Nückles, & Renkl, 2007; Graesser, McNamara, & VanLehn, 2005; Moos & Azevedo, 2008; Winne, 2006; van Merriënboer & Kirschner, 2007; Zimmerman & Tsikalas, 2005). This research suggests that well-designed computer programs not only can produce deep learning outcomes but also can scaffold such metacognitive processes as goal setting, elaborating information, and monitoring learning progress. As Graesser et al. (2005) point out, students in normal classrooms or even in one-on-one tutoring sessions seldom spontaneously exhibit deep learning approaches such as inquiry and explanation-centered learning. As a consequence, there are a growing number of attempts to build computer-based environments that scaffold metacognitive processes associated with deep learning.

Examples of these environments include AutoTutor, developed by Graesser and his associates (e.g., Graesser et al., 2005a; Graesser, Person, Lu, Jeon, & McDaniel, 2005b); McNamara and associates' *iSTART* (e.g., McNamara, O'Reilly, Rowe, Boonthum, & Levinstein, 2007); and Betty's Brain from Biswas and associates (Biswas, Leelawong, Schwartz, Vye, and the Teachable Agents Group at Vanderbilt, 2005; Leelawong & Biswas, 2008). These and other programs incorporate multiple sophisticated technical features, such as computational linguistic modules for speech recognition, simulation and animation subprograms, and techniques such as latent semantic analysis (LSA) for representing and evaluating student knowledge. AutoTutor employs animated conversational agents that interact with students in natural language to guide inquiry, metacognition, and deep explanations. The iSTART program, used for developing reading comprehension strategies in high school and college students (Magliano, Todaro, Millis, Wiemer-Hastings, Kim, & McNamara, 2005; McNamara et al., 2007), teaches them to self-explain text meaning and use comprehension monitoring, inferencing, and elaboration strategies. Animated pedagogical agents model reading strategies and offer practice and feedback on self-explanations. Betty's Brain (Biswas et al., 2005; Leelawong & Biswas, 2008) supports student decision making about learning, structured knowledge development, and reflective skills. A unique feature of this program is that it uses teachable agents—that is, computer agents that students teach and, in the process, learn the content themselves.

Research shows that programs like these have considerable promise in their ability to instantiate key conditions of learning. Much like expert human tutoring, which has significant advantages over classroom instruction (Graesser et al., 2005b), they offer individualized coaching that includes modeling, assessment, and feedback on learning strategies. As such programs are further refined, they should become increasingly capable of helping learners acquire both complex content and the effective learning strategies that are the mark of the active, self-reflective learner.

Computer-Supported Collaborative Learning

The previous three sections provide excellent examples of how cognitive principles can inform educational technology design. Good technology design takes into account both the ways our cognitive system works (e.g., attention, working memory, and long-term memory) and how complex cognitive skills develop (e.g., need for supportive and JIT information; coaching and scaffolding for effective learning strategies). Good design works with, rather than against, our cognitive systems, promoting active processing but not overloading working memory.

Understanding how technology can affect individual cognition, however, is only part of the picture. Another area of growing interest is how technology can support learning in groups. Consider, for example, the following questions:

- How can technology be used to help students collaborate?
- What kinds of learner collaborations best promote individual and group learning?
- Can diverse viewpoints shared via technology serve as learning resources?

Questions like these focus on the social dimension of technology use and are closely tied to one of our book's primary themes—that social interaction is fundamental to cognitive growth. They are consistent with the *social cognitive point of view* discussed in Chapter 9, which stresses the key role of social interactions in developing knowledge and thought. Student collaborations and productive exchanges between teachers and students are among the most important of these. But how can technology facilitate such interactions?

Two influential early projects provide good illustrations of classroom-oriented applications of technology to support collaborative learning. These projects have foreshadowed today's strong interest in computer-supported collaborative learning (CSCL). The first, called *Adventures of Jasper Woodbury*, is an instructional series developed by Bransford and his associates aimed at improving the mathematical thinking of middle school students. The second is *CSILE* (Computer Supported Intentional Learning Environment), developed by Bereiter and Scardamalia and their associates at the University of Toronto. Each has been widely used and illustrates innovative uses of a technology system based on cognitive and social cognitive learning principles.

The Adventures of Jasper Woodbury Series

Tapping the growing emergence of social cognitive theory in the early 1990s, the Cognition and Technology Group at Vanderbilt (CTGV) developed an extended problem-based curriculum called the *Adventures of Jasper Woodbury* (the *Jasper* series). Each of a dozen *Jasper* adventures revolves around a complex math-oriented problem requiring extended effort to solve. Because of the problems' complexity (some contain more than a dozen subproblems), they are difficult to solve alone and so students need to work together in problem solving. *Jasper's* primary goals were to develop students' ability to reason, think critically, reflect, argue, and learn independently. Its approach was *anchored instruction* (CTGV, 1997); the "anchors" in *Jasper* were complex, video-based problems for students to solve. Because anchors typically had more than one right answer, students had to evaluate and defend their ideas as they searched for solutions.

For example, one of the *Jasper* adventures, *Rescue at Boone's Meadow*, focuses on concepts of distance, rate, and time. *Rescue* begins with Jasper's friend Larry teaching another friend, Emily, how to fly an ultralight plane. Jasper and his friends also discuss his planned fishing and camping trip to a remote area, Boone's Meadow, which he will reach by hiking in. As the adventure moves ahead, important *embedded data* are introduced—facts and numbers that will become critical later, such as who knows how to fly the ultralight, their weight, the plane's weight, its payload and gas consumption, the location and accessibility of Boone's Meadow, and so on. Having data like these meant that when students were trying to solve problems, they had to engage in reasoned decision making, not just exchange opinions.

The situation unfolds when Jasper, now on his camping trip, hears a gunshot, discovers a wounded eagle, and radios for help. In a complex scenario in which additional embedded data are revealed (e.g., speed limits on nearby highways and the weight of the bald eagle, around 15 pounds!), learners come to the central problem: Emily needs to find the quickest feasible way to get the eagle to Dr. Ramirez, a veterinarian in Cumberland City. Many solutions to this problem are possible, such as various people walking, driving, and flying the ultralight. Obviously, students would have to consider many different kinds of data, estimate such things as fuel consumption and travel time, and solve several subproblems in order to make the best choices about how to reach and transport the eagle.

Anchors like *Rescue at Boone's Meadow* foster many kinds of communication and forms of problem solving. These were expanded by extending *Jasper*'s design to include such approaches as a video series to link teachers and students across classrooms and schools, Internet-based feedback, and software tools for representing and visualizing information.

Multiple evaluations have shown that the knowledge of basic mathematical concepts (e.g., figuring area and decimals) of *Jasper* students typically is about the same as matched non-*Jasper* students, which would be expected since *Jasper* does not focus on specific math skills. But students in *Jasper* score better in word problems testing transfer; in identifying what needs to be considered in complex problems (e.g., answering questions like "What does Casey need to think about to figure out how long her trip will take?"); in problem subgoal comprehension (e.g., answering a question like "Why did Casey divide the distance from Broken Bow to Ainsworth by the speed she'll be driving?"); and in their attitudes toward math and its utility (CTGV, 1997).

CSILE/Knowledge Forum: A Collaborative Approach to Knowledge-Building

CSILE (Computer Supported Intentional Learning Environments) was designed by University of Toronto researchers to create a group-based multimedia environment to support inquiry, information search, and collaborative improvement of ideas. The goal was to form a **knowledge-building community,** a group of individuals dedicated to sharing and advancing the group's knowledge. Scientific research teams are good examples of knowledge-building communities; others might be company marketing teams, graduate research seminars, or film societies (Hewitt & Scardamalia, 1998; Scardamalia & Bereiter, 1994).

First developed in the late 1980s and deployed on networked computers, CSILE provided a collaborative environment in which students could enter text and notes, including graphics, about the topic under study. They also could read and comment on each other's notes, in the process building their own and others' knowledge. CSILE's design allowed students to easily generate "nodes" containing ideas, notes, and references tied to whatever topics are being studied and to interact with their classmates about these ideas. This feature basically consisted of a multimedia database containing the ongoing research of the class on a particular topic.

CSILE has been reengineered in recent years as an Internet-based commercial application called *Knowledge Forum* (Scardamalia, 2003, Scardamalia & Bereiter, 2006; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). *Knowledge Forum* retains the CSILE's key features—serving as a repository for student ideas and questions and providing a forum for exchanging ideas. As in earlier versions, students build on their classmates' ideas and questions, reference each other's work, and reorganize information in the database. The system's graphics capabilities support structural dimensions of knowledge building; for example, a "views" feature provides graphical organizers for notes. Notes can be added in one or more views, clustered together, and moved around to represent different organizing frameworks. *Knowledge Forum* also provides scaffolds, supports for analysis of texts, theory building, and debating.

Knowledge Forum embodies a number of important **design principles** for collaborative uses of technology, starting with the principle that effective peer interactions can improve inquiry into complex ideas. Another is that requiring students to come to a shared understanding stimulates them to pay attention to each other, answer each others' questions, and clarify their ideas. The technology offers opportunities to see and closely examine other students' work, a relatively rare occurrence in most classrooms. For example, students can see which notes are highly connected and which are not (Zhang et al., 2007). Students also can use a search capability to retrieve and organize their own or classmates' notes. Among the key roles *Knowledge Forum* teachers play are highlighting interesting student work and encouraging them to explore the system's database. They also remind students that, in order to make a real contribution to the group's mission, they need to know what the group knows.

Programs such as *Jasper* and CSILE/*Knowledge Forum* continue to be instructive models for design of computer-supported collaborative learning. Explicitly based on cognitive and social cognitive principles, their goal is student collaboration and deep understanding. Both rest on the assumption that when students interact on issues important to them, deep learning will result. Anchors, which are *Jasper's* focal point, are challenging, complex, multidimensional problems designed to generate problem-solving and communication activities. CSILE/*Knowledge Forum*, in contrast, begins with an empty knowledge base, but seeds it with an issue or issues that become the hub of information gathering, inquiry, and discussion. Both of these systems strongly emphasize learner contributions—the information they have gathered, their perspectives on that information, and their reactions to others' viewpoints. Each uses technology to stimulate individual cognitive growth through the participation and growing sophistication of a community of learners.

As Internet-based technologies continue to improve, CSCL has emerged as an identifiable branch of the learning sciences focused specifically on how people learn together with computer support (e.g., Stahl et al., 2006). New collaborative programs also continue to appear. In Linn's WISE (Web-based Inquiry Science Environment) project (Linn, 2005; Slotta, 2004), for example, students respond to scientific controversies, such as global warming or recycling. With students working together in a Web-based environment and teachers playing a supportive role, WISE provides evidence and hints about the topic; notes, visualization, discussion, and assessment tools; and prompts for collaboration, reflection, and design of solutions.

Although CSCL offers avenues to deep learning, challenges remain. Flexible, theory-based collaboration systems such as *Jasper, Knowledge Forum*, and WISE typically have been developed within large research projects and have been more widely available for research than for general use. Even though commercial course management systems such as *Blackboard* with collaboration-supporting features are used extensively, their collaborative dimensions tend to be underutilized, as instructors typically use them primarily to post information such as syllabi and course resources (Ansorge & Bendus, 2003). In general, online teaching offers excellent opportunities for collaborative learning, but building collaborative dimensions into courses requires both a strong commitment and skillful integration of curriculum, collaborative teaching methods, and technology (Stahl et al., 2006).

Technology and Assessment

Computers have played an important role in assessment for many years, most obviously in standardized testing, which is supported by such technology-dependent activities as automated test scoring, item analysis software, and online applications of item response theory (the basis for automated item selection in computerized test administrations). Technological support for classroom assessment has lagged, however, perhaps because the barriers to it are formidable.

Creating a technology tool to assess and give feedback on student writing, for instance, not only requires highly advanced computer technologies but also deep understanding of the underlying linguistic and cognitive theories. At this point, both domains mostly have been beyond our reach and so we continue, as have generations of educators, to be constrained by time and energy limitations in our desire to provide rich feedback.

Recent research and development, however, give indication that this is likely to change—if not immediately, then in the not-distant future. Techniques such as latent semantic analysis (LSA, Landauer & Dumais, 1997) are being used in testing and computerized tutoring to represent text meanings and gauge comprehension (e.g., Graesser, et al., 2005b; Magliano, Millis, & McNamara, 2003, McNamara, Levinstein, & Boonthum, 2004; Millis, Magliano, & Todaro, 2006; Srihari et al., 2008). Utilizing complex statistical procedures, LSA can provide indices of semantic similarity of texts, for example, between a student's essay and a set of hand-scored essays. LSA-based automated scoring techniques have been shown to match the accuracy of human judgments of such variables as essay grades, text coherence, and document similarity.

In research hinting at future uses of technology to assess complex cognitive processes, Millis et al. (2006) had undergraduates make comprehension-related comments sentence-by-sentence as they read scientific texts (e.g., *The Origin of Coal*). These comments then were matched by LSA to (1) the current sentence being read and (2) other, earlier sentences, previously judged either to be immediate (local) or distant (distal) causes of the current sentence. Millis et al. posited that, because comprehending science texts requires understanding causal relationships, student comments showing ties to distal causes would be evidence for higher comprehension, while comments focused on the current sentence would not. This in fact was what the data showed. Reading comprehension—as measured independently—was highest when students talked more about causal ties to the current sentence than about the sentence itself. In this way an automated technology-based approach can provide an index of whether students comprehend what they are reading.

In research exploring practical uses of technology in assessment, Srihari et al. (2008) assembled a system of advanced technologies to test the feasibility of automated scoring of handwritten student essays. The technologies chosen included some for document imaging and recognition (e.g., to recognize and read children's handwritten words), and others (e.g., LSA) for automated essay scoring. When used on handwritten fifth and eighth graders' essays from a statewide reading comprehension test, the computer-based system provided a good match to human scoring and to scoring based on perfect transcriptions, evidence for the practicality of automated scoring of children's handwritten documents.

As these technologies and their theoretical foundations in cognitive science and linguistics continue to advance, one can envision future conversational computer-based assessment and tutoring systems providing intelligent feedback to students about what they say and write. Other systems can be foreseen that prompt student note taking about what they're reading and give students feedback on the quality of their notes or summaries. Still others might provide students with detailed reactions to their idea development and organization as they write an essay. While classroom and home uses of such systems still lie in the future, it seems highly likely that they will become available to offer students and teachers much needed assistance.

Implications for Instruction

We began this chapter by describing technology's uses in education and outlining key cognitive skills that can help students take advantage of technology. Cognitive theory is essential for judging whether specific uses of technology by either individuals or groups are likely to facilitate learning and cognitive growth. The following implications draw on this discussion, with special emphasis on work of Atkinson and Renkl (2007), Clark (2003), Graesser et al. (2005a), and Merrill (2000):

1. *Use cognitive principles as criteria for judging technology-based instruction.* As technology-based educational applications rapidly multiply, educators increasingly need to make informed decisions about their purchase and use. Market forces will ensure that virtually all educational technologies will be attractively designed and function well. The key questions for educators, however, should be whether programs will produce desired student learning, motivation, strategic behaviors, and metacognitive development. Does a technology-based program targeted at beginning readers, for example, represent a solid literacy curriculum and will its activities produce meaningful learning? Does it scaffold appropriate activities and meaningful student decisions? Are its demonstrations clear and screens designed to avoid excessive cognitive load? Does its content connect appropriately to children's prior knowledge? Questions like these are essential for distinguishing between computer-based instruction of dubious educational value that merely entertains and instruction that will develop important knowledge and skills.

2. *Emphasize technology's sense-making uses.* From a cognitive perspective, technology's best uses are those that produce meaningful learning. Technology provides a resource for achieving such cognitively oriented goals as finding and organizing information, discussing and refining concepts, and presenting ideas. For example, students working on a group project in an eleventh-grade environmental studies class might use Google, Bing, or another search engine to look for the latest information from the Centers for Disease Control and Prevention for a project focusing on Lyme disease, put state-by-state data into a spreadsheet, graph the growth of cases by region since 2007, share this information with other members of their working group to get their reactions, and create pages for the school Web site, perhaps even including some animations. Booklets could be created using publishing software, along with a Keynote presentation for parents' night. Activities like these—each involving significant technology use—are likely to produce deeper learning because students aren't just looking at information, they are making sense of it by using it and communicating it to others.

3. *Support authentic, challenging tasks with technology.* Long-term projects in which technology is used to accomplish project tasks can create many opportunities for extended, motivated intellectual activity. Tasks focusing on learning by doing, with information supporting skilled performance, are most likely to produce complex cognitive skills (van Merriënboer et al., 2002; van Merriënboer & Kirschner, 2007). Having students work on such tasks moves teachers away from the role of information presenter toward coaching and guidance roles, where they can help students develop habits of goal setting, monitoring, and reflection that lead to cognitive growth.

4. *Use technology to create and support collaborative learning communities.* Technology can provide a hub for learner interactions—planning collaboratively, sharing ideas across workgroups and classrooms, building on each other's ideas, getting feedback from classmates, and presenting ideas. These interactions, which focus on important content and data and take place over extended periods, are the building blocks for learning communities and create a context for cognitive growth.

5. *Use technology as appropriate to provide practice and feedback.* Many current commercial instructional programs—especially those designed for students with learning, language, and reading difficulties—focus on skill development through practice. Although there is a legitimate worry about "drill and kill," where students endlessly practice skills of dubious value, the computer actually can be an ideal partner for some kinds of practice (see van Merriënboer & Kirschner, 2007). Technology can present information, prompt responses, and give feedback to learners—all without tiring. For example, in a software application developed by one of the present authors, preservice teachers can practice judging samples of children's writing. As they rate multiple writing samples from different grades on several criteria and receive expert feedback on their ratings, they not only learn to accurately judge the quality of student writing, but also build their self-efficacy for making student writing a part of their future instruction (Dempsey, PytlikZillig, & Bruning, 2005, 2009).

6. *Help disabled students access and make use of assistive technologies.* Assistive technology can provide the critical support many disabled students require to achieve success. While assistive technologies cannot remove the difficulties that come with having a disability, they can assist students in meeting many classroom challenges. A rapidly growing number of versatile and powerful assistive technologies are available, ranging from tools for organizing information to speech recognition and text-to-speech conversion programs that increase opportunities for those with literacy-related disabilities to achieve classroom success.

Summary

This chapter is about new technologies, cognitive psychology's relationship to them, and their utility for learning and teaching. The chapter begins by exploring ways students can use technology and outlines key cognitive skills they need to take advantage of it. Several cognitive theories and sets of related research are discussed in relation to technology design and use. Among them are cognitive load theory, which focuses on working memory; the 4C/ID model, which is a cognitively based design framework for developing complex skills; metacognitive and self-regulated learning theory, which supports designs that scaffold goal setting and monitoring processes; and social cognitive theory, which informs many features of CSCL. Whereas cognitive load theory, the 4C/ID model, and metacognitive theory most directly apply to individual learning, social cognitive theory focuses on interactions among learners and provides a framework for creating technology-based learning communities. The chapter concludes with sections on technology as a growing factor in assessment and a section describing implications aimed at helping teachers and students use technology effectively.

SUGGESTED READINGS

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Richard Clark, a leading authority on learning outcomes and multimedia, analyzes a number of claims about Web-based learning in light of what research actually shows.

Moreno, R. (2005). Instructional technology: Promise and pitfalls. In L. M. PytlikZillig, M. Bodvarsson, & R. Bruning (Eds.), *Technology-based education: Bringing researchers and practitioners together*. Greenwich, CT: Information Age.
In this chapter, Roxana Moreno presents an expansion of her and Richard Mayer's cognitive-affective theory of learning with media, along with 10 principles derived from their research for guiding the design of instructional multimedia.

van Merriënboer, J. J. G., Clark, R. E., & de Croock, M. B. M. (2002). Blueprints for complex learning: The 4C/ID model. *Educational Technology Research and Development, 54 (1)*, 39–64.
This article, which gave wider dissemination to the 4C/ID model, provides a fine overview of how complex skills can be analyzed and how instructional technology systems should be designed for developing complex skills.

van Merriënboer, J. J. G., & Kirschner, P. (2007). *Ten steps to complex learning: A systematic approach to four-component instructional design*. Mahwah, NJ: Erlbaum.
Written to give guidance to designers of complex multimedia training, this book details 10 steps embedded in the 4C/ID model that designers should take to move from a training problem to a technology-based training solution.