INTRODUCTION

What are the characteristics of academically successful students? Successful college students have built an extensive knowledge base, but what is perhaps even more significant, they possess a vast repertoire of strategies for accessing their knowledge and for acquiring new information to add to their knowledge base. As they study, they are able to monitor when they do not understand and know when and how to use effective strategies to improve their understanding. When they are assigned a large project or paper, they exhibit the necessary planning and organization skills to complete the project in a timely fashion. These behaviors are indicators of high levels of metacognitive knowledge and skill. Given that sophisticated metacognition is a quality found in academically successful students, one way to support the development of academic skills in students is to foster the development of metacognition. This chapter focuses on metacognitive knowledge and skills as they develop in older, more experienced and skilled students (middle school, high school, college students) and instructional methods that support the development of metacognition. For a review of the development of metacognition in younger students and novice learners, consult Dimmitt and McCormick (in press).

We begin the chapter by examining various definitions of metacognition and how the prevailing perspectives on metacognition fit together with the related constructs of executive function and self-regulation. Next we describe some of the methods and approaches used by researchers to measure metacognition in their studies. Then we summarize research on metacognition in learning contexts, beginning with a consideration of general versus domain-specific metacognitive knowledge and skills. We then review research on metacognition in specific academic disciplines and on effective instructional methods to increase metacognitive knowledge and skills. We also address the role of teachers in supporting and modeling metacognition in their classrooms and methods for scaffolding metacognition in computer-based learning environments. Finally, we conclude with a discussion of likely future directions in theories of and research on metacognition.

DEFINITION OF METACOGNITION

Metacognition emerged as a specific focus of research in the early 1970s, although the knowledge and skills underlying this construct have been observed by educators and psychologists for decades and originate in the theoretical insights proffered by James, Piaget, and Vygotsky (Fox & Riconscente, 2008). John Flavell (1976) proposed an early definition of metacognition as “knowledge concerning one’s own cognitive processes and products or anything related to them” (p. 232), which he later condensed to what he termed the core meaning of “cognition about cognition” (Flavell, 1985, p. 104) or to use the common vernacular, “thinking about thinking.” This
definition seems simple and intuitive but an examination of the research literature on metacognition makes it evident that some researchers and theorists operate with different working definitions of metacognition. In their review of the research literature on metacognition and self-regulated learning, Dinsmore, Alexander, and Loughlin (2008) reported that researchers provided an explicit definition of metacognition in only 32% of the 255 studies reviewed.

How researchers defined metacognition and the particular components they emphasized in their definition often depended on the theoretical tradition of the researcher (cognitive developmental, cognitive science, educational psychology, social learning, cognitive behavioral, sociocultural) and the types of learning tasks studied. The context within which researchers operate influences how they frame the construct of metacognition and how they understand the relationship of metacognition to other related theoretical concepts. In general, however, metacognitive researchers tend to identify two facets of metacognition, knowledge about cognition and control over cognition (Veenman, Van Hout-Wolters, & Afferbach, 2006), but how metacognitive knowledge and control is conceptualized varies widely. For example, coming from a cognitive developmental approach, in an influential article, Jacobs and Paris (1987) delineated declarative, procedural, and conditional aspects of metacognitive knowledge. Declarative metacognitive knowledge refers to knowledge about cognitive processes and about factors that affect cognitive processing. Learners vary in the quality of their declarative knowledge depending on a variety of factors including age and ability. Procedural metacognitive knowledge refers to knowledge of how to execute procedures such as learning strategies. The procedural knowledge of skilled learners is more automatic, accurate, and effective than that of unskilled learners. Conditional metacognitive knowledge refers to knowledge about when and why to use procedures or strategies. The conditional knowledge of successful learners allows them to be flexible and independent in their strategy use. Jacobs and Paris also articulated the processes comprising metacognitive control. Planning involves the selection of a strategy or plan of action to achieve a goal. Evaluation refers to monitoring the process made toward achieving the goal. Regulation includes the revision or modification of the strategies to achieve the goal.

Alternatively, cognitive scientists studying metacognition in controlled learning situations, such as paired-associate learning, tended to be guided by the Nelson and Narens (e.g., 1990, 1994) model of metacognition, which makes a distinction between “object-level” where cognition occurs and “meta-level,” which oversees “object-level.” In this model, metacognitive knowledge is supported by the metacognitive processes of monitoring and control (Dunlosky & Metcalfe, 2009; Schwartz & Bacon, 2008). Monitoring processes, such as assessing progress and judging the likelihood of success, convey information about the object-level to the meta-level. Instructions from the meta-level are conveyed to object-level through control processes, such as the regulation of cognitive activity and the actions taken to support task completion, including adjustment of the approaches taken or strategies used and the allocation of resources, such as study time. Although this approach emerges from a vastly different research tradition, similar to other approaches described above, the emphasis is on a distinction between metacognitive knowledge and processes of monitoring and control.

Metacognition and Self-Regulation

The theoretical origins of the concept of metacognition as articulated by Flavell, Paris can be traced to cognitive developmental psychology, whereas the study of self-regulation emerged from social learning and cognitive behavioral theory and research (Dinsmore, Alexander, & Loughlin, 2008). The underlying theoretical approach is reflected in a basic distinction between the two constructs. Metacognition is concerned with cognition, the knowledge and control of cognitive processes, and thought and learning processes. Self-regulation, the broader concept, also encompasses behavioral and emotional regulation, most notably motivation (see Schunk & Zimmerman, this volume).

As Zimmerman (1995) argued, “Self-regulation involves more than metacognitive knowledge and skill, it involves an underlying sense of self-efficacy and personal agency and the motivational and behavioral processes to put these self-beliefs into effect” (p. 217). A learner could have well-developed metacognitive knowledge, but be unable to self-regulate in a specific context. Self-regulated learning refers to the “capability to mobilize, direct, and sustain one’s instructional efforts” (p. 217). So self-regulated learning is “more than metacognitive knowledge and skill, it involves a sense of personal agency to regulate other sources of personal influence (e.g., emotional processes and behavioral and social—environmental sources of influence” (p. 218).

Despite this apparent clarity in distinguishing between metacognition and self-regulation, in their review of the research, Dinsmore et al. (2008) reported considerable
overlap in the terms researchers use to define the two constructs and in the measures they use to assess metacognition and self-regulation.

A new model of self-regulation proposed by Efklides (2011), the metacognitive and affective self-regulated learning (MASRLo) model, highlighted the close linkage of metacognition and affect with cognition. Efklides argued that models of self-regulation vary in terms of whether the self is the basic organizing principle, top-down processing, or whether the task is the organizing principle, bottom-up processing, with self as the background. In contrast, the MASRL model posits two levels of functioning, the Person level and the Person X Task level. The Person level encompasses cognitive ability, including metacognitive knowledge (MK) and metacognitive skills (MS). MK is the representation of cognition; MS are the means to control cognition. Metacognitive skills include orientation strategies, planning strategies, strategies for regulation of cognitive processing, strategies for monitoring execution of planned action, and strategies for evaluating the outcome. The Task X Person level is where learning events occur, including metacognitive experiences (ME), such as a feeling of difficulty and online affective states. ME experiences during task processing include active MK and metacognitive judgments and feelings. The MASRL model reflects a growing consensus that metacognition is most easily understood as an essential component of self-regulated learning.

Metacognition and Executive Function

Executive function, which includes aspects of both metacognition and self-regulation, is another theoretical perspective that has become increasingly prominent in education and psychology. The concept of executive function emerged from the work of neuropsychologists in clinical practice as they identified deficits in cognitive functioning observed in their clients with brain injuries, ADHD, and autism spectrum disorders (Meltzer, 2007). As a result, executive function is studied much more in clinical populations, with less attention given to understanding executive function in the general population. Thus, the research focus has been on identifying and measuring deficits in executive functioning, using tools such as neuropsychological batteries and brain-imaging techniques. Researchers and clinicians have identified deficits in executive function skills, but have yet to reach agreement on a precise definition of executive function or consensus on a list of specific executive skills (Fischer & Daley, 2007; Meltzer & Krishnan, 2007).

Drawing from various models of executive function and applying them to educational contexts, Dawson and Guare (2010) described executive skills as organized around thinking skills and skills to guide behavior oriented toward achieving a goal. Executive thinking skills include planning, organization, time management, working memory, and metacognition. Executive skills to guide behavior include response inhibition, self-regulation of affect (emotional control), sustained attention, task initiation, flexibility, and goal-directed persistence. Thus, metacognitive constructs can fit within the executive function theoretical framework and self-regulated learning models, which typically emphasize motivational constructs, feature the executive function processes that are particularly relevant to applied learning settings. Some researchers would argue that executive function is the superordinate theoretical construct; others suggest that evidence exists supporting an overlapping relationship rather than a hierarchical one (Garner, 2009).

In summary, despite significant progress in articulating the relationship between metacognition and other related constructs since McCormick (2003), “fuzzy” boundaries between the related concepts of metacognition, self-regulation, and executive function still exist. Although researchers tend to draw on the theoretical distinctions present in the research tradition most relevant to their respective fields, increasing awareness of the multiple theoretical perspectives and greater communication between disciplines portends substantial movement toward the long sought comprehensive and unified theory of metacognition (Schraw, 2000). Much of the research reviewed in this chapter evolved from the developmental and educational psychology perspectives and from research focused on self-regulated learning in classroom contexts, although some of the research produced by cognitive psychologists studying metacognition in controlled learning situations is also included. Throughout this chapter, whenever possible, we highlight the theoretical distinctions made in the research reviewed.

ASSESSMENT OF METACOGNITION

Not surprisingly, given the various perspectives on the definition of metacognition, and the intermingling of metacognition with related concepts such as self-regulation and executive function, researchers have taken a number of different approaches to measuring the construct. Some measures of metacognition include indices of actual performance, such as calibration techniques where learners’
predictions are compared to their actual performance. Other measures, including a variety of metacognitive questionnaires, ask learners to self-report their usual metacognitive activities, typically out of context from any actual cognitive task. Still other researchers create their own informal measures to use in a specific context. Assessments of metacognition also differ in terms of whether they are measures presented offline, presented before or after task performance, or online, presented during task performance. Each method has its proponents and its characteristic strengths and weaknesses.

Verbal Report Methods

Verbal report methods, such as interviews and think-aloud protocols, are used to externalize metacognitive knowledge and process. Interviews are retrospective (offline) verbalizations of metacognitive knowledge and control; think-alouds are concurrent (online) verbalizations of thoughts and cognitive processes while performing a task. Some researchers argue that online measures are more predictive of actual learning performance than offline measures (Veenman et al., 2006; Wirth & Leutner, 2008).

One criticism of metacognitive interviews is that they are less accurate sources of information because they take place at a time distant from the actual processing. Think-alouds, on the other hand, are concurrent with learning activity but the process of describing the cognition as it occurs may, in fact, disrupt or alter the cognitive activity. One way to make interviews more adjacent to actual processing situations is to include hypothetical situations designed to elicit responses in the interview protocol. Another technique for increasing the accuracy of metacognitive interviews is to stimulate recall by asking learners to comment as they watch a videotape of a previous cognitive activity. In this interview combined with simulated recall, the cognitive activity is real, not hypothetical, and although the interview is distant, vivid memory prompts are available in the videotape, which may increase the accuracy of the recollections.

Verbal report methods, such as think-alouds and interviews, can be cumbersome in terms of administration and scoring, typically requiring detailed verbal protocol analysis. Researchers using such techniques develop rubrics to help them analyze their data. For example, Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo, Cromley & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004) developed a rubric to analyze the data of students who are asked to think-aloud while studying complex systems in hypermedia environments. This rubric consists of five categories of activity including planning, monitoring, strategy usage, task difficulty and interest. Each of these categories contains multiple activities that students may engage in while studying in a hypermedia system. The planning, monitoring and task difficulty categories are most directly related to metacognition and include actions such as judgment of learning, feeling of knowing, self-questioning, monitoring progress toward goals, and time-and-effort planning.

Metacognitive Questionnaires

Other researchers have focused on developing questionnaires to assess metacognitive knowledge and behaviors. Questionnaires have the advantages of being easier to use with large groups of students, are less time-consuming to score, and can be readily quantified for analysis. Concerns, however, have been raised about the potential for response bias, specifically the social desirability of responses, and about whether or not the scores on questionnaires are closely related to learning outcomes (Richardson, 2004). As Pintrich (2004) noted, metacognitive questionnaires can assess aptitudes or propensities but do not measure actual metacognitive performance. Nonetheless metacognitive questionnaires are featured in many metacognitive studies.

One of the most widely used questionnaires, the Motivated Strategies for Learning Questionnaire (MSLQ), was developed by Paul Pintrich and Wilbert J. McKeachie, evolving from a social cognitive theoretical perspective and through a multiyear program of research, to assess student motivation and use of learning strategies situated in classroom settings (Pintrich, 2004; Pintrich, Smith, Garcia, & McKeachie, 1993). An initial purpose of the 81-item self-report instrument was to assess the effectiveness of courses on students, with an underlying assumption that students’ responses would vary as a result of course experiences. The MSLQ, uses a 7-point Likert-type scale, 1 (not at all true of me) to 7 (very true of me), and consists of motivational scales (31 items, six subscales) and learning strategies scales (50 items, 9 subscales). The learning strategies scales include subscales assessing cognitive, metacognitive, and resource management strategies. The cognitive strategies subscale includes an assessment of rehearsal, elaboration, and organization strategies, as well as critical thinking. The metacognitive strategies subscale assesses planning, monitoring, and regulating. The resource management subscale refers to managing time and the study environment, the regulation of effort, peer learning, and help-seeking behavior.
In their retrospective on the development of the MSLQ and its subsequent impact on educational research, Duncan and McKeachie (2005) characterized the MSLQ as an efficient practical, ecological valid, well- established measure that has been used widely, in hundreds of studies, particularly in evaluations of university courses offered by offices of student affairs. Versions of the MSLQ have been created in other languages (e.g., Lee, Zhang, & Yin, 2010) and a shorter version (44 item) was developed for younger (junior high school) students (Pintrich & DeGroot, 1990).

Building from the primary theoretical distinction between knowledge and control of cognitive processes in the definition of metacognition described earlier, Schraw and Dennison developed another prominent metacognitive questionnaire, the Metacognitive Awareness Inventory (MAI), to measure the knowledge of cognition and the regulation of cognition in adolescents and adults (Schraw & Dennison, 1994). The MAI is comprised of 52 Likert-scale items (5-point), divided into two scales, knowledge of cognition and regulation of cognition. Factor analysis indicated that the two factors (knowledge and regulation of metacognition) were reliable and intercorrelated. Knowledge refers to the awareness of strengths and weaknesses, knowledge of strategies, and conditional knowledge (the “why” and “when” of strategy use). To assess knowledge and regulation of metacognition in younger students (grades 3 to 9), Sperling, Howard, Miller, and Murphy (2002) created the Jr. MAI, a 12-item scale with a three-choice response (never, sometimes, or always).

Researchers interested in metacognitive processing during test taking developed a metacognitive scale, the State Post Thinking Questionnaire (O’Neil & Abedi, 1996), which measures state metacognition experienced by students while completing cognitive assessments. The instrument has four subscales measuring different aspects of metacognition during test-taking, awareness, cognitive strategy, planning, and self-checking. Research with community college students and 12th-grade students has indicated that higher levels of state medication, as measured by this instrument, led to better test performance.

Other questionnaires have been developed to assess metacognitive in specific content domains such as reading and science. For example, Mokhtari and Reichard (2002) designed the Metacognitive Awareness of Reading Strategies Inventory (MARSII) to assess adolescent and adult readers’ metacognitive awareness and perceived use of academic reading strategies. The scale consists of global reading strategies (13 items)—strategies for global analysis of text, problem-solving strategies (8 items)—strategies for solving problems when text becomes difficult to read, and support reading strategies (9 items)—use of practical support strategies such as taking notes, accessing reference materials. Another measure focusing on reading processes is the Metacomprehension Scale (MCS), which consists of 22 Likert-scale (5-point) statements about seven components of reading comprehension abilities and strategies (Moore, Zabrucky, & Commander, 1997). The seven subscales are regulation (methods of resolving comprehension failures), strategy (techniques to improve comprehension), tasks (knowledge of basic comprehension processes), capacity (perception of comprehension abilities), anxiety (stress related to comprehension performance), achievement (importance of good comprehension skills), and locus (control of reading skills). Thomas, Anderson, and Nashon (2008) developed a bilingual instrument (English and traditional Chinese) to assess science students’ metacognition, self-efficacy, and learning processes. Exploratory factor analysis and Rasch analyses resulted in a 30-item, 5-subscale instrument called the SEMLI-S. One of the subscales (9 items), monitoring, evaluation, and planning (MEP) clearly assesses metacognitive processes in science learning.

Learning strategies inventories are a related category of questionnaires found in the research literature on academic skills, most prominently, the LASSI—Learning and Study Strategies Inventory (Weinstein, Zimmerman, & Palmer, 1988), but also the Study Process Questionnaire—SPQ (Biggs, 1987). Study strategy inventories, often used in undergraduate study skills courses to diagnose student strengths and weaknesses, tend not to focus on metacognitive processes explicitly although some recently developed study strategy inventories, such as the ILS, the Inventory of Learning Styles (Vermunt & Vermetten, 2004) and ALSI, the Approaches to Learning and Studying Inventory, include subscales measuring metacognitive processes (see Entwistle & McCune, 2004, for a review).

Although not an extensive body of research, some researchers have explored the interrelationships between various measures of metacognition. Sperling, Howard, Staley, and DuBois (2004) examined the interrelationships between the MAI, the MSLQ and the Learning Strategies Survey (LSS) (a study strategies inventory developed by Kardas & Amlund, 1991). They replicated the finding that knowledge of metacognition and regulation of metacognition are strongly related (e.g., Schraw & Dennison, 1994) and found a significant correlation between scores on the MAI and scores on the MSLQ. Vrugt and Oort (2008) studied metacognition, achievement goals, and study strategies of first-year college students exploring pathways that best predicted academic achievement.
(course performance as measured by a multiple choice and essay exam). They used the MSLQ, the MAI, and a shortened form of the Awareness of Independent Learning Inventory (AILI), an instrument developed and used more extensively in Europe (Elshout-Mohr et al., 2004, as cited in Vrugt & Oort, 2008) to measure knowledge of cognition (knowledge of person, strategies, and study tasks), regulation of cognition (planning, monitoring, and evaluation), and responsiveness (representing metacognitive experiences). The results indicated that students’ metacognitive knowledge and regulation of cognitive activities contributed to the selection and use of study strategies and two categories of study strategies, metacognitive and resource management strategies, had positive effects on exam performance.

Judgments of Performance

Schraw (2009) outlined a taxonomy of metacognitive judgments of performance, including prospective judgments (before testing), concurrent judgments (during testing), and retrospective judgments (after testing). Researchers employing calibration techniques have used different measures to indicate the goodness of fit between these judgments and actual performance. A key distinction is between absolute accuracy and relative accuracy. Absolute accuracy refers to whether or not a confidence judgment matches performance exactly, providing information about direction and magnitude of error; relative accuracy measures the relationship between confidence judgments and corresponding performance scores using some sort of correlation technique.

Nelson (1999) described three types of prospective monitoring—that is the monitoring of future memory performance. The Ease-of-Learning Judgment (EOL) refers to a judgment made before studying. The learner evaluates how easy or difficult an item will be to learn. For example, someone preparing to study a list of French vocabulary might predict that learning “chateau” means “castle” would be easier than learning “boite” means “box.” EOL predictions tend to be moderately correlated with actual recall. A second type of monitoring is assessed by a Judgment of Learning (JOL), which is a judgment during or soon after study about future recall. The learner predicts the likelihood of remembering an item on a future test. For example, someone might be asked to predict how confident they are that they will be able to recall English translation “box” when given the French word “boite” on a future test. Typically, learners are more accurate in their JOL predictions than in their EOL predictions.

Moreover, one consistent finding is that if JOL is delayed (e.g., 5 minutes after study), the delayed prediction is more accurate than immediate JOL (e.g., Nelson & Dunlosky, 1991; see also Rhodes & Tabor, 2011, for a meta-analytic review of this research). The third type of monitoring is assessed by a Feeling of Knowing (FOK), which is a judgment of the likelihood of future recognition of currently forgotten information after a recall attempt. Klin, Guzman, and Levine (1997) reported that FOK judgments for items that cannot be recalled are often good predictors of future recognition accuracy. Nelson also described retrospective confidence judgments, which are predictions that occur after a recall or recognition performance. On these tasks, there is a tendency for overconfidence—especially on recognition tasks (Nelson, 1999).

The Knowledge Monitoring Assessment (KMA), developed by Everson and Tobias (2001; Tobias & Everson, 2000, 2009), is another prospective measure of the relationship between predicted and actual performance that has been used in a variety of content domains. For example, in studies of vocabulary knowledge, students were given a list of vocabulary words in a content domain and asked to indicate the words they know and those they did not know. This estimate of knowledge was followed by a vocabulary test on the same words. The accurate metacognitive judgments of college students (items they said they knew and did and items they said they did not know and did) were positively correlated with standardized measures of language skills and to college GPA. The KMA has also been used to assess metacognitive monitoring of knowledge in other content domains such as mathematics (both word and computation problems) and students at all levels (elementary, middle school, high school, and college) have participated in the studies (Tobias & Everson, 2009).

In summary, this brief review of metacognitive measures supports the conclusion reached by Pintrich, Wolters, and Baxter (2000) in their more extensive review—there is no one “perfect” measure of metacognition. Different instruments measure different aspects of metacognition and all have their strengths and weaknesses. Some measure general metacognitive knowledge and skills, while others focus on metacognition in specific domains, a theoretical and applied issue taken up in the next section. In general, however, we need more longitudinal research designs and research with diverse populations to trace the growth of metacognitive knowledge and skills and to explore potential individual differences. Given the lack of a single generally accepted measure of metacognition, some researchers recommend employing multiple
methods, converging dependent measures, and advocate for the empirical investigation of the relationship among different measures (Cornoldi, 1998; Schraw, 2000, 2009).

GENERAL AND DOMAIN-SPECIFIC METACOGNITIVE KNOWLEDGE AND SKILLS

Depending on the field of research and the related definition of metacognition, debate continues about whether metacognitive knowledge and skills are developed in specific domains and then generalized, or whether broad skills are learned and then applied to unique contexts depending on the demands of the learning context, or both. Pintrich (2002) posited that students with general metacognitive knowledge and skills can use those when facing novel classroom tasks, facilitating the transfer of learning. Veenman et al. (2006) hypothesized that students may have broadly applicable general metacognitive knowledge about themselves as learners, what it means to learn, and how to learn something, and that knowledge may then be applied somewhat uniquely within different contexts. In apparent support of a general metacognitive skill, Schraw and Nietfeld (1998) found that college students who were skilled learners seem to have general monitoring skills that they were able to apply across learning contexts. Alternatively, Keleman, Frost, and Weaver (2000) studied memory monitoring in college students across a variety of tasks and found a low correlation for metacognitive accuracy across tasks and high variability in accuracy depending on the task and student ability, suggesting that both individual differences and contextual demands are important factors.

Research findings on the general versus domain-specificity issue have varied depending on which metacognitive knowledge and skills were under consideration, what methods of assessment were used, and the grain of analysis (Veenman et al., 2006). In part, the outcomes have also depended on whether metacognition is understood to be a set of cognitive skills that are a component of intelligence, a completely separate set of cognitive skills, or a somewhat unique set of cognitive skills that are highly correlated with intelligence but also separate (Veenman & Spaans, 2005). Increasingly, the research is suggesting that a combined model is most accurate, with considerable overlap between cognitive and metacognitive skills, but with metacognition providing additional improvement in academic performance above and beyond intellectual ability (Veenman & Verheij, 2003; Veenman, Wilhelm, & Beishuizen, 2004). Thus, there may be highly intelligent students who have not learned or do not use metacognitive strategies, and students with relatively weak cognitive ability who nonetheless use metacognitive strategies to good avail. This distinction may help to explain why there are not stronger correlations between general intelligence and academic functioning (Vrijs & Oort, 2008).

In adolescent and adult learners, metacognitive knowledge seems to be both general and domain specific. Broadly applicable metacognitive knowledge that most students have by the end of high school includes information about effective reading and writing strategies for texts in general (Harris, Santangelo, & Graham, 2010; Hartman, 2001a), and about general memory strategies such as reviewing academic content to increase retention (Schneider, 2010). Pintrich (2002) hypothesized that general metacognitive declarative knowledge domains included rehearsal (repetition to support memorization), elaboration (summarizing, paraphrasing, mnemonic and selection strategies), and organization skills (outlining, concept mapping, and note taking). General conditional knowledge that is applicable across contexts includes knowing when and how to use each specific metacognitive strategy to optimize outcomes (Schraw, Crippen, & Hartley, 2006). Declarative knowledge and beliefs about one’s skills in general and in a specific domain area impact behavior as well (Marsh, Martin, & Xu, in press; Zimmerman, 1989).

Procedural knowledge about oneself as a learner also seems to be both general and specific (Carr, 2010). For example, students may have general information about how to study, and may also have more specific knowledge about how and when one needs to study for a math test in ways that are distinct from knowledge about how and when one needs to study for an English exam. To be successful, then, students need knowledge about themselves as learners overall and in specific content areas, as well as how to study both generally and for a specific learning task. College students seem to be able to differentiate between metacognitive knowledge in general—“how most people learn and study”—and knowledge about themselves—“how I learn and study” (Pintrich, Wolters, & Baxter, 2000).

Having knowledge is not enough—in fact, many students have metacognitive knowledge they do not use (Dunlosky, Rawson, & Middleton, 2005; Maki, 1998)—that knowledge must then be appropriately and accurately applied in a relevant learning context. Winne and Nesbit (2010), in a summary of cognitive factors in academic achievement, have suggested that metacognition is a two-step process including initial
monitoring of a learning situation, and then making more or less informed choices about subsequent behaviors in the learning process. In Winne and Nesbit’s model, metacognition involves being alert to occasions to monitor, having and also choosing appropriate standards for monitoring, accurately interpreting what is being monitored, and having and also choosing appropriate strategies. Additionally, students then must be motivated to act and must create or find a context that allows for strategy implementation. These last two factors are usually considered to be components of self-regulation and not metacognition, however (Winne & Nesbit, 2010).

Cognitive development and experience are generally believed to support increases in general, more global cognitive executive skills and processes such as planning, goal-setting, monitoring, strategy selection, and strategy use. As they develop, students learn new strategies, become more efficient in the strategies they use, and also generally stop using strategies that seem ineffective (Kuhn, 2000; see also Dimmitt & McCormick, in press). But not all students use metacognitive processes. Leutwyler (2009) found that by the last year of high school, 51% of the 1,432 Swiss students in his study reported using planning strategies to learn, 59% used evaluating strategies, and 81% used some form of monitoring strategies. In this study, differences were not observed by socioeconomic status (determined by the number of books in the home) but there were consistent gender differences, with girls reporting higher use of all three metacognitive strategies in both 10th and 12th grade (Leutwyler, 2009). College students also may not exhibit consistent metacognitive knowledge or strategy use (Hofer, Yu, & Pintrich, 1998; McCabe, 2011). Moreover college students may or may not be aware of strategies, and if aware, may not have the expertise to effectively use them (Justice & Dorman, 2001).

Students with general metacognitive knowledge and skills are more able to apply active learning strategies in a variety of academic contexts and when faced with an unfamiliar learning task (Pintrich, 2002; Schraw, 2001), which becomes increasingly important in secondary and post-secondary learning environments. As academic domains become increasingly differentiated, task demands, learning processes, and assessment of learning become more domain specific. For example, studying for an English test may call for the use of memory strategies for vocabulary words, while studying for a calculus exam may require practicing calculation. Both may require monitoring for comprehension, review of material, and decisions about whether the content is adequately mastered. For these reasons, Baker and Beall (2009) suggested that students need to learn both general and domain-specific metacognitive skills, with the latter embedded in the relevant context in order to support learning.

Of particular interest to educators are questions about how students develop the metacognitive knowledge and skills relevant to academic success both across and within learning domains, what helps students choose to use the skills they have, and how to teach these skills effectively. The next few sections of this chapter will summarize the relevant research in these areas, starting with reading comprehension skills, which are a foundation for many learning tasks.

**Metacognition and Reading**

Reading is a complex and multidimensional process that requires phonemic awareness, decoding, fluency, word recognition, use of prior word and world knowledge, active comprehension strategies, and monitoring (Pressley, 2006). Once basic reading fluency skills are achieved, effective readers approach the task of reading knowing and being able to use a range of strategies. They know how to read effectively, can identify the purpose of reading, and know how to make sure they understand and then remember what they have read (Kamil, Mosenthal, Pearson, & Barr, 2000; National Reading Panel, 2000; Pressley & Afflerbach, 1995), all of which are metacognitive components of the task. Research using the think-aloud protocol has demonstrated that as skilled readers read they enter texts with some predictions about the context based on context variables such as setting and prior related knowledge (Pressley, 2003). While reading, effective readers also can recognize when they do not understand the content, generate questions, adjust their strategies accordingly, and realize when they need to ask for help (Otero, 2009; Pressley, 2003). When they are done reading, they can summarize what they have read, make inferences, and think about how to use the ideas in other contexts (McKeown & Beck, 2009; Pressley, 2003). Conversely, reading research has shown consistently that when students read without using these metacognitive strategies they are less likely to understand what they have read (Brown, Armbruster, & Baker, 1986; Dunlosky & Lipko, 2007), are more likely to misinterpret the content (McKeown & Beck, 1994) and are less likely to remember what they read (Griffin, Wiley, & Thiede, 2008).

A complete summary of the research on the development of students’ knowledge and use of metacognitive processes in reading is beyond the scope of this chapter, and has been done elsewhere (see National Reading Panel,
context-specific, and may require specialized vocabulary and context knowledge for comprehension. Students who set reading goals and actively use reading comprehension strategies such as looking for the main idea in a text, summarizing, generating questions, note taking and underlining had higher GPAs in college (Taraban, Rynearson, & Kerr, 2000). Students who successfully use metacognition are able to accurately identify the learning context demands, set goals accordingly, choose specific learning/studying behaviors to enact that they believe will help them reach their goals, self-monitor their success in moving toward their goals and meeting the demands, change their strategies when what they are doing doesn’t work, and determine whether they have reached their goals (Winne & Nesbit, 2010).

Calibration techniques, described earlier, have been used to assess metacognition related to the comprehension of textual material, although judgments about the complex task of learning connected discourse are generally less accurate than those associated with the more simple task of paired-associate learning (Pieschl, 2009). Calibration of comprehension, sometimes termed metacomprehension, is operationalized by relating readers’ predictions of comprehension with actual performance on a test. High correlations indicate good metacomprehension; low correlations indicate poor metacomprehension. In a typical study using this paradigm, Maki and Berry (1984) asked college students to read paragraphs from an introductory psychology text. After reading each paragraph, the students predicted (on a Likert-type scale), how well they would perform on a multiple-choice test. For the students who scored above the median (the better learners), the mean ratings of material related to questions answered correctly were higher than ratings of material related to questions answered incorrectly. Students are more accurate in their calibrations of comprehension when more test questions are provided per prediction (Weaver, 1990) and when asked to make multiple judgments (Weaver & Bryant, 1995). Although delayed predictions and delayed tests produce the highest prediction accuracy in paired associate learning, the classic Delayed Judgment of Learning effect (JOL) described earlier, immediate predictions and immediate tests produce the greatest prediction accuracy with text material (Maki, 1998).

Maki (1998) reported that the mean gamma correlation between predictions of test performance and actual test performance across many studies (more than 20) emanating from her lab was .27, a low level of relative accuracy. Moreover, the metacomprehension accuracy of college students varies by the type of text being read (Maki,
Shields, Wheeler, & Zaccchilli, 2005; Wiley, Griffin & Thiede, 2005). Zhao and Linderholm (2008) explored potential explanations for limits on metacomprehension suggesting that learners judge future comprehension performance by starting with an anchor (performance expectations based on past history) and adjust that performance expectations as a result of experience with the task at hand.

Retrospective judgments of learning have also been studied with textual material. Glenberg and Epstein (1985) asked college students to rate how well they would be able to use what they learned from textual material to draw an inference. They found that the only judgments more accurate than chance were postdictions (those made after responding to the inference questions). Pressley and Ghatala (1990) also found more accurate predictions of learning after testing, something they called the “testing effect.” Similarly, Maki (1998) reported that many studies indicate that predictions made after taking a test (postdictions) were more accurate than predictions preceding a test (see also Pieschl, 2009).

Researchers have identified individual variation in the metacomprehension accuracy of college students (Chiang, Therriault, & Franks, 2010). Student characteristics, such as verbal ability, have an effect on prospective and retrospective judgments of learning. For example, Maki, Shields, Wheeler, and Zaccchilli (2005) asked students who varied in verbal ability to predict future performance both before test and after test. On hard tasks, the students with lower verbal ability were overconfident; students with higher verbal abilities were underconfident about past performance. Metacomprehension accuracy also varies with student performance in undergraduate courses. Hacker, Bol, Horgan, and Rakow (2000) studied undergraduate students in a semester-long course. High-performing students were accurate and their accuracy improved over the semester. Low-performing students exhibited moderate prediction accuracy but good postdiction accuracy and they were generally overconfident in their predictions and postdictions. Hacker, Bol, and Babahani (2008), studying calibration in an undergraduate educational psychology course, also found that higher performing students were accurate in their predictions and did not find significant improvement in accuracy over the semester. Lower performance students were less accurate than higher performing students in their calibration and when provided with extrinsic incentives, showed improvement during the semester. Miller and Geraci (2011) studied college students’ predictions of their performance on course exams and their confidence in these predictions. In comparison to high performing students, the lower performing students were more overconfident in their predictions (predicting higher performance than their actual performance) but were less confident in their predictions, thereby indicating that they had some inkling that they had been overconfident.

**Metacognition and Writing**

The very act of writing itself has recently been hypothesized to be a process of applied metacognition (Hacker, Keener, & Kircher, 2009). These authors define writing as “the production of thought for oneself or others under the direction of one’s goal-directed metacognitive monitoring and control, and the translation of that thought into an external symbolic representation” (Hacker et al., 2009, p. 154). According to this paradigm, writing is textual, cognitive, and social, and it is both a process and a product. Writing is an “act of meaning production” (p. 157) that involves use of metacognitive monitoring strategies through “reading, reviewing, reflecting, and revising” (p. 157) and the use of metacognitive control strategies through “editing, drafting, idea generation, word production, translation, and revising” (p. 157). Hacker et al. (2009) argued that the explicit and implicit use of these strategies is both a metacognitive process and what translates one’s thoughts into writing—hence, writing as applied metacognition.

Using think-aloud protocol analysis, Hayes and Flower (1980; Flower & Hayes, 1981), developed an early model of the role of metacognition in writing. They described writing as a recursive, interactive, goal-directed thinking process involving planning, translating ideas and images into words, reviewing what has been written, and monitoring throughout the process. Flower’s revision of this model has focused on the process of creating meaning through interpretation, negotiation and reflection (Flower, 1994). Hayes’ revisions have focused on content comprehension, the role of affect and motivation, writing task definition, the evaluation, revision and interpretation of text, and the role of memory resources (Hayes, 1996, 2006). Hacker et al. (2009) argue that the writing process is less hierarchical and more constantly recursive than the original Hayes and Flower model, and that the very act of writing requires continuous active control and monitoring processes.

Scardamalia and Bereiter (1986; Bereiter & Scardamalia, 1987) generated another influential theoretical model that posited that writing involves creating a mental representation of the writing task, problem analysis and goal-setting, problem translation, and composing. This
model differentiates between two broad strategies for composing: knowledge telling and knowledge transforming. In knowledge telling, a strategy used more often by novice writers, what is known about a topic is presented in a paper until the supply of knowledge is exhausted. In knowledge transforming, used by more expert writers, the writer consciously reworks the text—diagnosing problems, planning solutions, and monitoring the effectiveness of solutions.

Since this early theorizing, much writing research has focused on the differences between more and less skilled writers, in order to both explicate writing processes and to determine how to teach students how to write more effectively (Graham, 2006). This research has consistently found that effective writers have a repertoire of metacognitive knowledge and control strategies that aid them in every aspect of the writing process (Harris, Graham, Brindle, & Sandmel, 2009; Sitko, 1998). Good writers carry out advance planning, organize their ideas and text, have more understanding of the writing process, and have strategies for drafting and revising their writing—ultimately creating more coherent, polished, articulate and effective texts (Harris et al., 2009).

**Metacognition and Problem Solving in Science and Mathematics**

Effective problem solving is another academic activity that has been consistently found to require considerable metacognitive knowledge and skill (Carr, 2010; Davidson & Sternberg, 1998). In Davidson and Sternberg's (1998) model of general problem solving, the critical first step is to define what the problem is, including the formation of a mental representation that would be helpful to solving the problem. An effective mental representation allows the problem solver to organize and combine information (thus decreasing memory demands), to monitor solution strategies, and to allow generalizations across problems. A mental representation that encourages generalization would be based on essential, rather than surface, features of the problem. After problem definition, an appropriate solution strategy must be selected and then monitored as it is implemented. If there are obstacles to solving the problem, they must be identified and addressed. Experts in a specific domain spend proportionately more time analyzing, planning, and determining possible strategies than do novices (Schoenfeld, 1987), and their problem representations tend to be more abstract than those of novices (Davidson, Deuser, & Sternberg, 1994).

Some researchers have argued that metacognitive processes are involved in almost every aspect of problem solving in mathematics (Desoete, 2009). In math, metacognitive skills are needed in order to apply a learned strategy to new but related problems, to make predictions (a version of goal setting), to monitor and to judge the appropriateness of a chosen strategy and to make different strategy choices when necessary (Desoete). More proficient math students are more likely to use metacognitive strategies to solve problems and reason (Lucangeli & Cornoldi, 1997), to solve word problems (Teong, 2002), and to determine whether they know how to do specific kinds of math questions (Desoete & Roeyers, 2006).

Science is another academic discipline where metacognitive knowledge and strategies, especially in problem solving, have proven to be critical. Scientific learning and exploration, especially inquiry based learning, is often conceptualized as particularly related to metacognitive processes (Schraw et al., 2006; White, Frederiksen, & Collins, 2009). White and Frederiksen (1998, 2005) developed a model of scientific inquiry that integrates theory and empirical investigation, with four interrelated and recursive components, each with metacognitive features. *Meta-theoretic knowledge* involves information about the scientific theories and models (including structural, causal, and dynamic models) used to guide inquiry, as well as "how theories and models are created, refined, and coordinated" (White et al., 2009, p. 180). *Meta-questioning knowledge* entails understanding a wide range of research questions, and how scientific questions contribute to the expansion of existing theories and models and to the development of new ones. Meta-questioning knowledge also includes hypothesis-generation, and the awareness of the complex relationships among scientific questions *meta-investigation knowledge* subsumes information about the forms of scientific investigation, including both exploratory (inductive) investigations and confirmatory (hypothetico-deductive) investigations of hypotheses. Included in this is attentiveness to the strengths and weaknesses of each kind of investigation. *Meta-knowledge for data analysis* includes information about "(a) the representation of data, (b) the confirmation or refutation of existing hypotheses, (c) the induction of new hypotheses, and (d) generalization" (White et al. 2009, p. 183).

**INSTRUCTIONAL INTERVENTIONS**

Metacognitive awareness and skills are a central part of many academic tasks, leading to a critical question
for educators about how we foster the development of metacognition in students. Veenman et al. (2006) identified three principles for successful metacognitive instruction: a) embedding metacognitive instruction in the content matter to ensure connectivity, b) informing learners about the usefulness of metacognitive activities to make them exert the initial extra effort, and c) prolonged training to guarantee the smooth and maintained application of metacognitive activity” (p. 9).

Research on metacognitive instruction has been conducted at multiple levels—with individual students, at the classroom level through curriculum, and at the classroom level through general teaching practices. According to Paris and Winograd (1990), the cognitive reflection required to develop sophisticated metacognition can “come from within the individual or from other people” (p. 21). Thus, researchers have explored techniques for fostering metacognition that involve solo learners and that utilize interactions between learners to encourage the development of metacognitive thought. Research has also been across contexts, including laboratory settings, in actual classrooms, and with computers. What has become increasingly clear is that students need to learn multiple strategies (although not so many as to be confusing, Pressley, 2000), to be able to use strategies alone and with others, and to have awareness of the contextual demands that are the best match for each specific strategy (Baker, 2002; Gajria, Jitendra, Sood, & Sacks, 2007; National Institute of Child Health and Human Development, 2000). What follows is a description of successful educational interventions with middle school and high school students and then with college students.

Middle School and High School Students

Because metacognition involves consciousness of one’s own thinking, instructional interventions have focused on strategies designed to make cognitive content and processes more accessible and explicit, especially in the core skills of reading, writing and problem-solving. Explicit instruction in metacognitive strategies increases student use (Bransford, Brown & Cocking, 2000; Schneider & Pressley, 1997), and increased use leads to greater engagement in both academic and nonacademic learning (Zimmerman, 2001) as well as to better academic outcomes (Brown, 1997; Tobias & Everson, 2009).

A full discussion of the extensive body of research about metacognitive strategy instruction that improves reading comprehension skills is beyond the scope of this chapter. There is evidence that teaching students methods for making thinking processes more visible and concrete, such as self-instruction (Miller, Giovenco, & Rentiers, 1987) thinking aloud (Baumann, Seifert-Kessel, & Jones, 1992), and self-explanation (McNamara & Magliano, 2009) are effective. In addition, reading intervention programs such as Self-Explanation Reading Training (SERT; McNamara, 2004) and Interactive Strategy Training for Active Reading and Thinking (iSTART; McNamara, O’Reilly, Best, & Ozuru, 2006) have been designed to promote self-explanation and other metacognitive reading strategies including monitoring comprehension, making bridging inferences, paraphrasing, predicting, and elaborating (McNamara & Magliano, 2009). Several studies have demonstrated positive outcomes for the SERT and iSTART interventions with high school and college students, with stronger results for students with less prior knowledge and measures of comprehension that were more text-based (McNamara & Magliano, 2009; O’Reilly, Best, & McNamara, 2004).

Teaching specific strategies can have an impact, but increasingly programs designed to improve reading and comprehension either teach multiple metacognitive strategies or teach how to metacognitively monitor and regulate several related cognitive strategies (Williams & Atkins, 2009). One of the first such programs was Informed Strategies for Learning (ISL) (Paris, Cross, & Lipson, 1984; Paris & Jacobs, 1984), which was designed to teach students specific regulation strategies through modeling, discussion, and scaffolded guided practice. Another early method was reciprocal teaching (RT), an instructional model designed for teaching comprehension strategies in the context of a reading group (Brown & Palincsar, 1989; Palincsar & Brown, 1984). In RT students learn to make predictions during reading, to question themselves about the text, to seek clarification when confused, and to summarize content. The teacher models the process, then students provide peer modeling for each other. The underlying premise is that by participating in this group learning process, students eventually internalize the strategies, and the evidence is that reciprocal teaching is generally effective (Rosenshine & Meister, 1994).

The “Questioning the Author” (QtA) method of reading comprehension and comprehension-monitoring development is based on cognitive processing models more than strategy instruction per se (Beck & McKeown, 2006; McKeown & Beck, 2009). QtA uses open questioning by teachers to facilitate engagement with the content of a text, and particularly the most salient ideas, in order to facilitate comprehension. It is designed to help students generate mental models about ideas in a text in order to facilitate
comprehension, with a focus on reading content rather than specific cognitive strategies. Studies at the elementary and middle school level have found that QtA helps students seek connections, build meaning, and articulate ideas about complex texts, with related increases in both comprehension and comprehension-monitoring (Beck & McKeown, 2006; McKeown & Beck, 2009).

King (1997, 1998, 2002) developed the ASK to THINK—TELWHY®® model of peer tutoring to promote reciprocal inquiry to foster skill development in asking deep questions, answering questions in order to develop one's own and others' learning, building on another's response, and assessing one's own and others' understanding and comprehension. In addition to supporting comprehension and monitoring of text, metacognitive questions in this model develop explicit identification of strategy use, and help learners to identify possible retrieval and memory cues for subsequent use of the material (King, 2002).

The research on reading comprehension strategy instruction has demonstrated that instruction impacts several student outcomes, and that metacognitive skills can be improved. Questions remain about which specific strategies or groups of strategies are most effective in varying learning domains, for learners of each age, for learners with differing abilities, for types of text, and for the difficulty of the text involved.

Effective writing instruction also includes components related to the development of metacognition. Graham and Perin (2007) conducted a meta-analysis of writing instruction methods for adolescents and concluded with 10 research-based recommendations, several of which involve metacognitive processes such as planning, revising and editing compositions, and summarizing reading material. The results of the meta-analysis demonstrated that metacognition is a significant factor in writing, and that strategies instruction can improve writing and the related metacognitive components that underlie effective writing (Graham & Perin, 2007).

One of the most widely researched metacognitive strategy instruction models in writing is Self-Regulated Strategy Development (SRSD; Graham & Harris, 2003; for a review see Harris et al., 2009), which has been studied for over 20 years. There are six stages to the model: Teachers activate and develop student background knowledge; discuss the writing processes and strategies to be used in each writing task; explicitly model each stage of the writing process (generating ideas, planning, organizing ideas, writing, and revising) and related strategies for success (through think alouds or other demonstration of metacognitive processes); provide time and memory strategy for students to memorize the writing strategies; provide scaffolded support of use of the strategies through guided practice, and; provide opportunities for students to perform independently (Harris & Graham, 1992).

SRSD has been found to be effective with writers with a range of skills, in a variety of writing genres, and from grades 2 through 10. SRSD generates significant improvement in “development of planning and revising strategies, including brainstorming, self-monitoring, reading for information and semantic webbing, generating and organizing writing content, advanced planning and dictation, revising with peers, and revising for both substance and mechanics” (Harris et al., 2009, p. 145). The key components of the SRSD model identified by Harris et al. (2009) are that self-regulation and writing strategies are explicitly taught, students actively collaborate in their learning, instruction is modified based on learners’ needs, students are self-paced, with mastery as the goal, and instruction occurs over time, with new strategies introduced and known strategies reinforced.

Metacognitive strategy instruction has also produced impressive gains in student outcomes in scientific reasoning (Zohar & Peled, 2008), scientific inquiry skills (White & Frederiksen, 2005) and scientific literacy (Michalsky, Mevarech, & Haibi, 2009), which in this study was defined as the ability to access prior knowledge, ask questions and draw conclusions from scientific texts. In mathematics, metacognitive strategy instruction in self-questioning, problem-solving and monitoring can improve student learning outcomes (Delcrete & Harrington, 1991; Fuson, Kalchman, & Bransford, 2005; King, 1991).

College Students

Moving from a high school to a college learning environment triggers many academic challenges. At the college level, students are more often required to use and demonstrate higher order thinking skills, to be able to use new knowledge and not just remember information, to be independent learners, and to match their learning behaviors to the task demands. Successful college students are more likely to possess metacognitive skills such as the capacity to know when they have not adequately learned course material, to match their studying activity to the demands of the assessments of learning, and to estimate their understanding accurately (Hacker et al., 2000; Isaacson & Fujita, 2006).

Research has demonstrated that even sophisticated learners can misjudge or inaccurately interpret the
demands of a learning situation (Carroll, 2008; Garner & Alexander, 1989; Kruger & Dunning, 1999), that students who use metacognitive strategies are more likely to be successful in college (Everson & Tobias, 2001) and that education about metacognition and metacognitive strategies can increase student learning and related achievement (Bransford, Sherwood, Vye, & Rieser, 1986; Zimmerman & Moylan, 2009). Moreover, even proficient college-level readers can benefit from reading instruction (Lei, Rhinehart, Howard, & Cho, 2010) especially regarding comprehension (McNamara & Magliano, 2009).

Dunlosky and Lipko (2007) summarized investigations of how metacognition performance in college students can be improved. With college students, rereading is one strategy that has been found to improve both comprehension accuracy (Rawson, Dunlosky, & Thiede, 2000) and immediate recall (Roediger & Karpicke, 2005). Summarizing texts during reading and generating key terms representative of the text while reading have also increased the metacognition accuracy of college students (Thiede & Anderson, 2003; Thiede, Anderson, & Therriault, 2003; Thiede, Dunlosky, Griffin, & Wiley, 2005). Other effective techniques for increasing text comprehension monitoring and retention include responding to questions inserted in text (Pressley, Snyder, Levin, Murray & Ghatala, 1987) and self-testing, via writing about content just read (Roediger & Karpicke, 2005).

Other researchers have explored techniques that utilize interactions between learners to encourage the development of metacognitive skills. Based on a theoretical model of dyadic cooperative learning focusing on the acquisition of cognitive (C), affective (A), metacognitive (M), and social (S) skills (CAMS), O'Donnell, Dansereau, Hall, and Rocklin (1987) asked college students to read textual material working in scripted dyads, in unscripted dyads, or as a group of individuals. Scripted dyads were given instructions in how to interact with their partners. Specifically, they were taught to take turns as they read, having one person summarize the text section while the other tried to detect errors and omissions in the summary. O'Donnell et al. found that students who worked in dyads recalled more of the texts than individuals did. Scripted dyads, however, demonstrated greater metacognitive awareness in that they were more accurate in rating their performance than were the other students.

The think-aloud method has been used successfully in mathematics instruction, using a cooperative peer-learning model that resembles reciprocal teaching (Whimsey & Lochhead, 1986). One person reads a problem and solves it, saying steps in the process out loud. The other person listens and monitors the problem-solver's process. The monitor checks for accuracy, asks questions and identifies errors. The learners take turns in each role, developing skills in both problem solving and monitoring. Schoenfeld (1985) also developed a method for improving metacognitive skills during mathematical problem solving. Students are instructed to methodically break down and simplify problems, generate possible solutions or new ways of understanding it, and then identify solutions. At each step of the process, the students are taught monitoring and evaluating strategies so that they can self-evaluate their process and outcomes, resulting in significant improvement in students' problem-solving skills, more frequent self-monitoring while working, and more facility with novel problems.

Schraw, Crippen, and Hartley (2006) reviewed instructional strategies in science and identified six general areas that promote metacognition or other aspects of self-regulated learning: inquiry-based learning (students actively generate hypotheses and generate solutions), collaboration among students and teachers, strategy instruction (in cognitive, problem solving, and critical thinking strategies), developing mental models and awareness of conceptual change, the use of technology, and increasing awareness of student and teacher beliefs and their impact on science education.

Although the research instruction designed to foster metacognition is promising, it is important to keep in mind that there are consistent discrepancies between what students know is most effective and what they actually do. Karpicke, Butler, and Roediger (2009) found that even when students knew the more effective study strategy of active recall (a version of self-testing and retrieval) most of them chose to reread, which is a less impactful method. They theorized that students have illusions about their competence and make choices about study habits that reflect that overestimation of their ability and knowledge. Rereading suggests an illusionary ease with the learned content that leads to inaccurate assumptions of knowledge and capacity to recall content. The more effective strategy required active recall that is more similar to a testing requirement, and so is a more accurate self-assessment of what is known.

Finally, in a study examining both metacognitive awareness and instructional methods to increase that awareness in an applied college classroom context, McCabe (2011) first asked college students to judge the effectiveness of six empirically validated effective learning strategies as described in learning scenarios derived from research and found that students were not able to accurately predict the
effectiveness of most of the strategies (except for a "weak endorsement" of the strategy of generating study materials). Performance on this task was, however, correlated with the metacognitive regulation subscale of the MSLQ described earlier. In a second study, McCabe examined different levels of instruction on the effectiveness of the strategies and found that students who had received some kind of targeted instruction on applied memory topics in their psychology courses (in a single lecture, in a cognitive course with ongoing discussion of the topics, or in a seminar where original research about the six empirically validated strategies was discussed) exhibited higher prediction accuracy than control students or students who participated in the first study. The students who were the most accurate were the ones who read and discussed the relevant research. McCabe reached the following conclusion: college students' awareness of the effectiveness of strategies is relatively low and "educational intervention, in the form of targeted instruction on learning and memory topics, may have the potential to improve metacognitive awareness of factors associated with academic success" (p. 474).

**LEARNING ENVIRONMENTS TO PROMOTE METACOGNITION**

In addition to investigating the effectiveness of researcher-designed instructional interventions as reviewed in the previous section, researchers have also examined the characteristics of learning environments that promote the development of metacognitive knowledge and skills. Much of this work has focused on teacher-led learning environments, the more typical classroom context, resulting in an initial emergent understanding of the teacher behaviors that foster growth in metacognition. This work on teacher-led learning environments is complemented by preliminary explorations of how to best designed computer-based learning environments to support metacognition. Research focusing on teacher-led and computer-based learning environments is summarized in turn.

**Teacher-Led Learning Environments**

Teachers can use metacognition to improve their teaching processes and to create learning environments that are conducive to metacognitive skill development in students. Teaching metacognitively includes both "teaching with and for metacognition" (Hartman, 2001b, p. 149) and each of these approaches is elaborated below.

**Teaching for Metacognition**

When teachers "think about how their instruction will activate and develop their students' metacognition, or thinking about their own thinking as learners" that is teaching for metacognition. Such teaching "for" activities include planning, scaffolding, reflective questioning, providing timely feedback, modeling, explicit strategy explanation, and promoting collaborative learning and peer tutoring (Bransford et al., 2000; Hartman, 2001a). Teachers can also provide students with instruction in learning activities that support metacognitive development, such as setting goals, learning study strategies, analyzing errors, generating questions, organizing ideas, creating graphic organizers and evaluating work (Zimmerman & Moylan, 2009). Bransford et al. (2000) theorized that a metacognitive classroom environment is learner-centered, designed to promote student engagement and learning, and supports increasing amounts of student self-direction and self-regulation. Students in this context are challenged with complex tasks that build on prior knowledge and that require active and strategic learning and metacognitive deliberation (Bransford et al., 2000; Brown, 1997).

Sitko (1998) described the overall theme of metacognitive instruction as "making thinking visible." To this end, she suggested incorporating introspection, on-line thinking-aloud protocols, and retrospective interviews or questionnaires into classroom practice. Fesco and Fountain (1992) provided a shopping list of teaching techniques that they suggest are likely to foster the development of metacognition, including extended wait time, metacognitive questions, concept mapping, writing in journals, and think-aloud techniques in cooperative groups. They cautioned, however, that "unless these self-reflective strategies become a part of daily classroom tools, there is little chance that they will become students' strategies" (p. 240). Winograd and Gaskins (1992) emphasized that "metacognition is most likely to be invoked when individuals are pursuing goals they consider important" (p. 232). Thus, they argued for authentic activities and thoughtful assessment in classrooms. In addition, they recommended a combination of teaching methods, including cooperative learning and direct explanation for strategy instruction (Duffy & Roehler, 1989; Roehler & Duffy, 1984). Formative assessments that allow for immediate feedback and correction as well as self- and peer-assessments in addition to teacher assessments provide a variety of perspectives on students' work (Brown, 1997).

Schraw (2001) encouraged teachers to use an instructional aid he calls the Strategy Evaluation Matrix (SEM) for the development of metacognitive knowledge related
to strategy instruction. In this matrix, students list their accessible strategies and include information on How to Use, When to Use, and Why to Use each strategy. The idea is to foster the development of explicit declarative, procedural, and conditional knowledge about each strategy. In classroom practice a teacher can ask students to complete a SEM for strategies in their repertoire. Then the students can compare strategies in their matrix and compare their SEM to the matrices of other students. Schraw conceptualized the SEM as an aid to improve metacognitive knowledge and proposed the Regulatory Checklist (RC; modeled after King, 1991) for improving metacognitive control. The RC is a framework for self-questioning under the general categories of planning, monitoring, and evaluating. Schraw emphasized that providing students with the opportunity to practice and reflect is critical for successful implementation of these instructional aids.

Meichenbaum and Biemiller (1992) proposed that educational growth in a particular skill or content domain has two dimensions: the traditional curriculum sequence or “basic skills” dimension and the dimension of “classroom expertise,” where students overtly plan, monitor, and evaluate their work. To foster growth in the second dimension (the development of metacognition), they advised teachers to pay attention to pacing, to explicit labeling of task components, and to clear modeling of how to carry out tasks and problem solve. They cautioned that students should engage in tasks that vary along a range of complexity. Tasks that are too simple will not require extensive metacognitive processing, and excessively complex tasks will inhibit a student’s ability to self-talk metacognitively or to talk to others due to limits of attentional capacity.

Ritchhart, Turner, and Hadar (2009) found that when classroom teachers (grades 3 to 11) consistently modeled the process of making their own thinking more transparent that their students’ thought processes (as measured by concept maps about thinking) became more sophisticated and intentional, above and beyond expected changes due to maturation and development. Collaborative engagement with peers, especially when it is carefully set up with established questions, roles, and goals, has been found to be conducive to learning (Duffy, Miller, Parsons, & Meloth, 2009; Whitebread, Bingham, Grau, Pasternak, & Sangster, 2007) and can be motivating and engaging for students (Zimmerman & Moylan, 2009).

A line of research conducted by Duffy and his colleagues (Duffy, 2002; Duffy et al., 1986; Duffy et al., 1987) identified direct explanation of strategies by teachers as a key component of metacognitive strategy instruction in reading comprehension. The initial part of the intervention was teacher training in the use of direct explanation and subsequently teachers taught students the strategies, and talked about why and when they were useful. Teachers who were trained in strategy explanation were more specific in what and how they taught reading strategies, and their students showed greater declarative and procedural metacognitive knowledge (Duffy et al., 1986; Duffy et al., 1987).

The direct explanation of strategies is also a critical part of the Transactional Strategies Instruction (TSI) program developed by Pressley and colleagues (Brown, Pressley, Van Meter, & Schuder, 1996; Pressley, 2002b). This model starts with providing teachers with training in how to teach reading comprehension strategies, facilitate collaborative peer dialogue about strategy use, motivate students to use the strategies by making personal links to the text content, and support eventual independent strategy use by students. TSI has been found to impact reading comprehension on the Stanford Achievement Test (Brown et al., 1996), which is a rare finding for outcome studies of metacognitive reading strategy instruction (Williams & Atkins, 2009). In addition, TSI seems to support students’ positive identification of themselves as readers (Casteel, Isom, & Jordan, 2000).

Teaching With Metacognition

When teachers “think about their own thinking regarding instructional goals, teaching strategies, sequence, materials, students’ characteristics and needs, and other issues related to curriculum, instruction and assessment before, during and after lessons in order to maximize their instructional effectiveness” that is teaching with metacognition (Hartman, 2001b). Duffy, Miller, Parson, and Meloth (2009) recently suggested after a thorough review of research on teachers’ metacognitive thought processes that the most effective teachers “frequently and deliberately engage in conscious, mindful action (or, as we argue, in metacognitive thought) as well as technical or procedural routines” (p. 241). According to these researchers teaching requires all of the metacognitive knowledge, skills and strategies used by effective learners, and while teachers are engaged in this thinking about their own thinking and actions they must simultaneously also be aware of and make decisions about how to support the development of the thinking and learning of their students—a demanding set of tasks.

In describing the problems inherent in identifying and measuring teacher metacognitive processes, Duffy et al. (2009) articulated the following challenges: confusion and overlapping constructs in definitions of metacognition in
teacher education, the inherent complexity of the teaching task and context and related measurement, the routinization of many metacognitive tasks (especially by experienced teachers), external institutional and legislative requirements that impact teacher behaviors, and, finally, the methodological difficulties accessing intuitive thought, concurrently and retrospectively. In other words, the assessment challenges articulated earlier in this chapter are compounded by the demands of teaching.

Duffy et al. (2009) argued that several teacher activities, including planning, decision-making, scaffolding, and assessing learning are inherently metacognitive, although the thought processes of teachers engaged in these behaviors are not well researched, and there is little evidence of an impact on student outcomes. Studies of effective teachers and classrooms have indicated that planning for instruction, setting learning objectives, determining effective techniques to meet the objectives, and selecting methods for measuring whether students have learned what was intended all lead to substantial benefits for teachers and students (Berliner, 2004; Pressley, 2002a). At the same time, being able to be flexible, responsive to individual learner’s needs, and spontaneous are all part of successful teaching (Morrow, Tracey, Woo, & Pressley, 1999). Additionally, teaching for student metacognitive development using think-aloud modeling, direct instruction of strategies, and scaffolding of learning require pedagogical understanding of metacognition (Wilson & Bai, 2010).

Wilson and Bai (2010) surveyed 105 graduate students preparing to be teachers using the Teacher Metacognition survey created for their study. They found that the graduate students knew that instructional strategies support the development of student metacognition, were aware that metacognition and teaching metacognition are active processes requiring engagement and practice, and valued many metacognitive pedagogical approaches such as demonstration, scaffolding, and explicitly teaching strategies. A structural equation model found that there were complex and significant relationships among participants’ conditional, declarative and procedural metacognitive knowledge. All three types of knowledge also were related to pedagogical knowledge of metacognition. The researchers identified some contradictions between what the students knew about how to support metacognitive skill development and what they reported about how they planned to teach.

Based on their outcomes, Wilson and Bai (2010) questioned whether there is a tension between what their study participants knew they should do (teach with and for metacognition) and recognition of what they have seen done and actually do themselves in the classroom. They suggested that teaching metacognitively does not fit easily into educational contexts where there is pressure to cover a certain amount of content, and conclude, “These teachers appeared to have an academic understanding of what is necessary for teaching students to be metacognitive, but they also seem to value activities that are not highly correlated with helping students to be metacognitive” (p. 286).

If effective teaching, and particularly effective teaching for student metacognitive skill development, requires metacognitive awareness and skill in teachers, a key question is what education and professional development methods will facilitate development (Duffy et al., 2009; Wilson & Bai, 2010; see also Whitcomb in this volume). Some recent strategies that have shown promise include promoting metacognitive reflection in order to promote active engagement in and responsibility for learning (C. Glava & Glava, 2011), and concept mapping and Vee diagramming (Palak, 2011). Duffy et al. (2009) highlight the need for more research about how and when teachers are metacognitive, how teacher metacognition is related to student achievement, and how to provide both preservice and inservice teachers with effective education about metacognition—their own and their students’.

**Metacognition in Computer-Based Learning Environments**

Researchers are interested in exploring whether and how computer-based metacognitive scaffolds can be useful in improving overall student learning in computer-based learning environments (CBLs) at the middle school, high school and college levels (Goldman, this volume). This research is motivated by the increasing ubiquity of computers in educational settings and society at large, as well as the belief that computers can serve as cognitive tools to improve teaching and learning in many domains. Ultimately this research could lead to efficient and cost-effective ways to optimize student performance in a variety of learning situations, including those in which a competent human tutor is not available (e.g., in online learning courses, while undertaking homework, and/or in large classes) or where computer-based learning plays a prominent role (e.g., lab settings). Additionally, this research may prove helpful in addressing the achievement gap in education. For example, as computers become more and more available in school settings and access to CBLs increases, all students may have the opportunity to become better learners through the metacognitive scaffolds built into CBLs. Since the question of the relative
efficacy of human versus computer scaffolding is not a main concern of this research, a comparison to human tutors is rarely made.

Across the developmental span of interest, researchers have focused on two core issues: (1) the relationship of metacognition to learning complex topics in computer-based learning environments; and (2) the design of effective scaffolds embedded in computer-based learning environments (CBLEs). Two major findings, discussed in detail later, derive from these foci: first, students with strong self-regulated learning skills (including metacognitive skills) learn more than students with weak self-regulated learning skills when studying in complex CBLEs and second, adaptive scaffolds are more effective than fixed scaffolds in enabling student learning in CBLEs. The research discussed below suggests that computer-based, fixed scaffolds may be most effective when utilized in conjunction with both human and computer-based, adaptive scaffolds such as virtual agents. We now discuss each research focus in turn.

Metacognition and Learning Complex Topics in CBLEs

Past research has indicated that students have real difficulties learning complex topics in CBLEs (Shapiro & Niederhauser, 2004). This finding holds true for younger students as well as undergraduates (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Azevedo, Guthrie, & Seibert, 2004). CBLEs have multiple representations of content including text, diagrams, audio, images, animations and video material (Jacobson & Azevedo, 2008). One navigates a CBLE via hyperlinks; students are able to select their own path through the material. It is argued that this nonlinear presentation of the material in a CBLE places special demands on learners, for example, it may result in cognitive overload (Greene, Moos, Azevedo & Winters, 2008) and/or disorientation (Greene, Bolick, & Robertson, 2010; Puntambekar & Stylianou, 2005).

Azevedo, Cromley, and Seibert (2004) argued that the nonlinearity of CBLEs also places special metacognitive demands on learners. Indeed, students entering a CBLE must make metacognitive control decisions about which material to engage with first and which links are the most relevant to their specific line of inquiry. However, not many students have strong metacognitive monitoring and control abilities, two concepts that are at the heart of self-regulated learning theory (Hewden & Winne, 2001). Therefore, one method for helping students improve their ability to learn from computer-based learning systems is to improve their metacognitive self-regulation skills (Azevedo & Cromley, 2004).

Toward that end, Azevedo and his colleagues launched an ambitious research agenda focused on understanding students' use of self-regulated learning (SRL) skills while studying in a CBLE. A stated goal of this research was to develop CBLE design guidelines specific to metacognitive scaffolding. While this research has been framed as investigations of students' SRL skills, the majority of the SRL skills assessed in this research are metacognitive in nature. The research studies conducted by Azevedo and his colleagues have occurred at the middle school (Azevedo et al., 2008; Greene et al., 2008), high school (Azevedo, Cromley, Winters, Moos, & Greene, 2005; Greene, Bolick, & Robertson, 2010) and college level (Azevedo & Cromley, 2004; Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004) and they have focused on the learning of complex systems in science and history.

The initial study in this series was conducted by Azevedo, Guthrie, and Seibert (2004) as they sought to understand if there were differences in students' use of SRL skills while studying about a complex science topic in a CBLE: the human circulatory system; and if so, did this result in differences in students' development of a mental model of the circulatory system. During this initial study, the researchers developed their methodology for examining students' SRL skills, which they then used in numerous follow-up studies. This method included: pre- and posttests of declarative knowledge (matching, labeling, and drawing); pre- and postverbal examples of students' mental models of the circulatory system; and the gathering of think-aloud data from the students as they studied in the CBLE. The think-aloud data serve as a baseline measure of students' metacognitive capabilities inasmuch as they received no training in metacognition prior to the task and nothing in the CBLE was designed specifically to scaffold metacognition. The researchers constructed a robust rubric (discussed earlier in the chapter) that allowed them to analyze the relationship of students' SRL skill usage (including planning, monitoring, strategies, task difficulty and demands and interest) to their achievement as measured by declarative knowledge and mental model development about the circulatory system. The results of this initial study indicated that students did use different SRL skills while studying in a CBLE and that those who used more effective strategies and spent more time monitoring their learning demonstrated the greatest shift in terms of the completeness of their mental models of the circulatory system.

Based on the results of this study, Azevedo and Cromley (2004) investigated the effects of SRL training for
students on their learning in a CBLE. In this study, students in the treatment condition received a 30-minute training session on SRL skills prior to studying in the CBLE. Students in the control condition received no training. Those who received the training performed significantly better on most tests of declarative knowledge and mental model development after studying with the system. This was due to their superior use of effective SRL sub-strategies in the areas of planning, monitoring, and strategy enactment learned as a result of the training. Azevedo and Cromley suggest that computer-based learning systems that embed aspects of the SRL training may improve student learning of complex topics in CBLEs. Such embedded aspects include pretests to activate prior knowledge, access to planning tools that would allow students to plan their learning in relation to an expert-set of learning goals for the content, monitoring scaffolds that provide lists that students can compare against their own learning, and prompts that get students thinking about their feeling of knowing (prior knowledge) and judgment of learning ("Am I learning anything here?") as they are working in the environment.

**Human Adaptive Scaffolds Versus Fixed Scaffolds**

To further investigate the design of scaffolds for learning a complex topic in a CBLE, Azevedo, Cromley, and Seibert (2004) and Azevedo et al. (2005) investigated three levels of SRL scaffolding for learning in CBLEs: no scaffold, fixed scaffold, and adaptive scaffold. The first study was conducted with undergraduates, the second with high school students. In each study, the fixed scaffold condition consisted of provision of an overall learning goal for students and a list of ten questions to guide their inquiry as they studied the human circulatory system. The adaptive scaffold consisted of a human tutor who provided assistance to the student participants related to the use of SRL strategies in completing the task, but who did not give advice on the actual content of the CBLE. This assistance included help on planning and monitoring learning as well as using different strategies and handling difficult task demands. A third group of students in each study received no scaffolding. In both studies, tests of students’ understanding of the circulatory system revealed that participants in the adaptive scaffold condition learned the most. In the second study, students in the no-scaffolding condition outperformed students in the fixed scaffolding condition on tests of declarative knowledge and in mental model shift. The results of these two studies appear to indicate that certain types of fixed scaffolds (e.g., a provided list of prompts) in CBLEs may have little to no value for student learning. However, there are many types of computer-based, fixed scaffolds, some of which are more effective than others.

**Computer-Based Fixed Scaffolds**

Many studies have examined the use of fixed scaffolds in CBLEs and the research results on the effectiveness of these scaffolds are mixed. Research findings across the developmental span from middle school to undergraduate education do suggest that fixed scaffolds, which complement adaptive scaffolds (either human or computer-based adaptive scaffolds) are more effective than fixed scaffolds on their own.

Most CBLE fixed scaffolds consist of what Lin, Hmelo, Kinzer, and Secules (1999) described as: (a) process models (modeling metacognitive thinking processes that are usually tacit and unconscious); (b) process displays (displaying problem-solving and thought processes specific to the domain of study); and/or (c) process prompts (textual prompts that direct students’ attention to specific aspects of strategies while learning is in action). CBLEs may utilize a combination of process models, process displays, and process prompts.

Process models are generally instantiated as graphical displays (Manlove, Lazonder, & de Jong, 2007; White & Frederiksen, 2005), which utilize arrows to dynamically model the process students are undertaking; whereas, process displays have been operationalized as digital notebooks (Brush & Saye, 2001; Quintana, Zhang, & Krajcik, 2005; White & Frederiksen, 1998). Such notebooks provide students with a high-level, organizational overview of the activity in which they are about to take part. White and Frederiksen’s science-based CBLE, Inquiry Island, utilizes both process model (graphical displays) and process display (digital notebook) scaffolds. In addition to these computer-based, fixed scaffolds, the Inquiry Island curriculum intervention also included computer-based and human-based adaptive scaffolds. The computer-based adaptive scaffolds consisted of a multiagent system of advisors that could assist students in developing their metacognitive understanding. The human-based adaptive scaffolds consisted of students’ working in groups and taking on the roles of the metacognitive advisors found in the software itself, such as the role of reflector, as well as some teacher scaffolding of student reflection through question prompts. In a controlled experiment of the Inquiry Island curriculum, White and Frederiksen (2005) found that their metacognitive intervention was an effective means of increasing student achievement in science. However, this study’s outcome measures focused on
student learning of the process of inquiry and there was not an attempt to disentangle the relative contribution of each element of the designed environment/curriculum to this learning. Therefore, there is no independent confirmation that either the computer-based process model or process display fixed scaffolds were useful or to what degree they were useful.

In research on process displays embedded in Decision Point!, a CBLE about the Civil Rights Movement in the United States, Brush and Saye (2001) created a guided notebook to scaffold student understanding of the methods historians use to analyze historical events. The guided notebook consisted of data analysis categories that a historian might use to examine the event; the student could add information to these categories as they conducted their research. This method was applied to historical interactive essays made available in Decision Point!. In a qualitative study of student use of the system, Brush and Saye found that the guided notebook was largely ineffective because the students tended to record superficial information under the data analysis categories provided and they only took notes for about 50% of the interactive essays viewed.

Inquiry Island, Decision Point!, and other CBLEs have also used process prompts to urge students to either reflect on their own learning (usually in some form of journal) or to ponder questions or advice posed by the CBLE itself. For example, Brush and Saye (2001) used reflective prompts in Decision Point! to urge students to reflect on what they had learned in their history inquiries and/or to list the questions and concerns that had come up for them while working in the history CBLE. Brush and Saye found that the prompts to reflect in the journal, and the journal itself, similar to the guided notebook, were not effective interventions, in that many students either did not bother to use the journal, or only added superficial reflections. Importantly, Brush and Saye made a distinction between the metacognitive scaffolds embedded in the system (the guided notebook and the journal, which were largely ineffective) and conceptual scaffolds that were also embedded in the CBLE. The conceptual scaffolds included the interactive essay itself as well as a drop down menu list that highlighted important documents to be viewed related to the historical event under study. Brush and Saye reported that the conceptual scaffolds were more effective in supporting student learning in that students used them more often and reported finding them to be useful in their study of the Civil Rights movement.

While Brush and Saye (2001) reported mixed results in their research on fixed scaffolds in CBLEs, Manlove, Lazonder, and de Jong (2007) found that the fixed scaffolds (process model and process prompts—titled the Process Coordinator) provided in their physics-based CBLE inhibited student learning. While the treatment group’s final lab report had a better structure than the control group (which the researchers attributed to the metacognitive prompts) the students in the control condition outperformed students in the treatment condition in regard to the development of a runnable mental model of a fluid dynamics problem (the task required students to discover the physics-based factors that would influence the amount of time it would take for water to empty out of a tank through a drain hole). The authors provided two possible explanations for the negative result: first, the time it took for students in the treatment condition to work with the support functions may have impeded their mental model development, and/or second, students in the control condition utilized help files embedded in the system that may have had a direct benefit on mental model understanding. A third possibility not mentioned by the authors is that fixed scaffolds are perhaps most effective when complementing adaptive scaffolds.

For example, White and Frederiksen (1998) used fixed, textual prompts in their Thinker Tools CBLE to scaffold student thinking about science inquiry. However, students also had access to human scaffolding of their reflections. The students engaged in both private, computer-based self-assessment, and public, whole class assessment of peers' work. Peer assessment occurred at the end of each inquiry project when groups presented their work to the class. At this time, students provided both verbal and written feedback to their peers. Perhaps due to the fact that there was an added social and public element to the reflection process in the Thinker Tools curriculum, the outcomes for science inquiry learning were strong. In other words, reflective assessment in the Thinker Tools curriculum was an effective activity because the assessments included self and peer aspects, human and computer-based scaffolds, private and public elements, and the assessments were given both verbally and in writing; unlike the reflection journal in Decision Point!, which stood alone as a fixed scaffold that prompted private, self-reflection in writing only.

Success in learning with only fixed scaffolds was reported by Kim and Pedersen (2010). These researchers utilized structural equation modeling to examine their theory that both prior domain knowledge and metacognitive knowledge affects hypothesis development in science inquiry activities. In their study, they used self-questioning prompts to urge students to reflect on their learning process in the Animal Investigations CBLE. Kim and
Pedersen reported a good model fit of the data to their theory on the relevance of prior knowledge and metacognition to effective hypothesis development. Therefore, the fixed scaffolds in this study, in the form of self-questions, appear to have been helpful to students in terms of the development of metacognitive knowledge.

Alven and Koedinger (2002) also reported on the efficacy of fixed scaffolds. These researchers looked at student learning with a geometry tutor computer program. Students in the treatment condition received prompts to select an explanation of the problem they just solved from a drop-down menu. These students did significantly better on certain types of problems (reason and not-enough-information problems) than did students who were in a problem solving only condition. Also, students in the treatment condition developed greater levels of declarative knowledge (integrating visual and verbal aspects) while students in the control condition developed greater procedural knowledge.

**Computer-Based Adaptive Scaffolds**

In addition to the textual process prompts provided in the CBELEs discussed thus far, process prompts have also been provided by means of virtual agents. White and Frederiksen’s (2005) Inquiry Island CBLE is a multi-agent system that features several programmable advisors (Quentin the Questioner, Molly the Monitor, Pablo the Planner, and others) that provide metacognitive advice. For example, Quentin the Questioner provides advice on strategies to use when developing a research question such as, “Be uncertain about the answer: Does your question have an obvious answer? If so, why bother investigating it? Keep thinking until you come up with a question for which you aren’t sure about the answer” (White & Frederiksen, p. 213). These advisors are programmable. Students can add advice to an advisor and this advice becomes a part of the advisors’ repertoire; it can be given to students at a later time. In this way, the agent prompt scaffold in Inquiry Island becomes an adaptive scaffold. Due to this programmable aspect, the advisors can change in response to learner needs and abilities. They are adaptable to the needs of the students, and adapted by the students themselves—making this adaptive scaffold both computer- and human-based. In a study of the effectiveness of this curriculum in a fifth-grade classroom, the researchers found that students who were in the metacognitive advisor condition significantly improved their metacognitive abilities and their ability to do inquiry as compared to students who did the same inquiry project but did not use the Inquiry Island CBLE and, therefore, had no access to the adaptive scaffolds of the programmable, metacognitive advisors.

Molemaar, van Bostel, and Sleegers (2010) also conducted a study that utilized a virtual agent to prompt students’ metacognitive activity. Their study focused on how to increase the co-regulation of a group when learning in a CBLE in order to improve learning outcomes. The CBLE featured a three-dimensional virtual agent embedded in the learning environment. The researchers examined two types of scaffolds: structured or problematized. In the structured environment, the agent provides a worked example of how to create a mind map. In the problematized scaffold, the CBLE prompts the students to think about how to do the task by asking “How can you plan a mind map assignment?” These problematized scaffolds are meant to trigger metacognitive activity on the part of the students. The students in the study worked in an online environment to answer the question of whether they would like to live abroad in either New Zealand or Iceland. The scaffolds were timed to be delivered by the agent in relation to learner activity (orientation, planning, monitoring). The user could send information back to the agent in terms of a question mark, a happy, sad or neutral face. These two latter elements create an adaptive element to the scaffold. The researchers found that students in the problematized scaffold condition showed higher levels of metacognition and performed better on a near-transfer task. There were no other significant differences among the two conditions.

Biswas, Leelawong, Schwartz, Yye, and the Teachable Agents Group at Vanderbilt (2005) utilized the concept of a teachable agent to help students develop metacognitive understanding. In their study, students provided Betty, the teachable agent, with knowledge by creating a concept map about a river ecosystem. The developers provided Betty with metacognitive capabilities including the ability to monitor, assess, set goals, seek assistance, and reflect on feedback. Betty used these abilities to examine the chain of reasoning that was being built by the students as they developed the concept map and to remark to the students when the chain of reasoning did not make sense. The researchers found that in a controlled study, students in the metacognition condition demonstrated a better ability to learn new material and to complete a far transfer task.

Puntambekar and Stylianou (2005) also produced an adaptive scaffold computer environment. Their research focused on navigational issues that middle school students can run into while working in a web-based learning management system (LMS). The researchers conducted two studies. In the first study, they examined students'
navigational patterns as they traversed the LMS. From an analysis of this data, the researchers developed specific scaffolds to help other students more easily navigate the environment. These specific scaffolds were then provided to students in a second study as they navigated through the LMS. These scaffolds proved to be effective in impacting student learning in CBLIs. However, the time- and labor-intensive nature of this type of supportive scaffolding will only work on a large scale once the entire process of data collection and analysis of navigation patterns has been computerized. Also, more research is needed to understand whether such navigational help will reliably result in better learning outcomes for students.

Aleven and his colleagues have been working on developing adaptive scaffolds that are built on a help-seeking model. This help-seeking model works with a cognitive model in a cognitive tutor to provide metacognitive help at the moment it is needed (Aleven, McLaren, Roll, & Koedinger, 2006; Roll, Baker, Aleven, McLaren, & Koedinger, 2005). In this scenario, the help-seeking model attempts to understand “how” students go about seeking help in a CBLE and it works in conjunction with the cognitive model, which attempts to understand the students’ current cognitive comprehension of the problem at hand.

The help-seeking model has been developed based on two constructs: (1) the ideal help-seeking model (as derived from the work of Nelson-Le Gall, 1981; Newman, 1994), and (2) “gaming the system” behavior (Roll et al., 2005). The help-seeking model allows the tutor to monitor student activity in the system and present error messages when maladaptive metacognitive activity is sensed. Based on their empirical work with students using their tutors, the researchers have grouped maladaptive metacognitive behavior into four categories: (1) help abuse; (2) try-step abuse; (3) help avoidance; and (4) general bugs. Several subitems are listed in each category. For example in the help-abuse category, the researchers list: asking for a hint when should try, clicking through hints, ask for hint when should search for information, and information resource overuse. The gaming the system detector tracks whether or not the student is attempting to exploit regularities in the system, for example, clicking quickly through all hints to get to the “bottom out” hint, which essentially provides a worked example of the problem to the students. This second type of maladaptive metacognitive behavior is interesting in that students have to understand enough about the system in order to exploit it. This monitoring of a student’s help-seeking behavior provides the computer tutor system with information with which it can adaptively guide the student to actions that are more metacognitively sound, including self-questioning (What do I know? What do I need to know? How can I gain that information?).

Aleven et al. (2006) examined how well the help-seeking model predicted post-test scores on geometry assessments, based on the number of metacognitive errors committed by students. They found that the model did predict post-test scores. However, they also learned that the help-seeking tutor was offering too much advice to the students. As programmed, the help-seeking tutor provided feedback to students on 73% of their actions within the system. The researchers argued that this frequency of feedback may not be useful to students. Roll, Aleven, McLaren, Ryu, Baker, and Koedinger (2006) found that while the help-seeking tutor was successful in giving feedback on correcting metacognitive errors it did not lead to improved learning in the domain or to higher levels of declarative knowledge.

Due to these mixed findings about the effectiveness of the help-seeking tutor, Roll, Aleven, McLaren and Koedinger (2007) undertook research to examine whether or not the help-seeking tutor could lead to greater domain knowledge, better help-seeking behavior or higher levels of declarative help-seeking knowledge. They did this by creating two new elements for the help tutor—an update to the tutor that not only pointed out metacognitive errors to the students, with recommendations for what to do next, but also stressed the benefits of figuring out what one’s metacognitive errors are toward the goal of eliminating them. They also included classroom instruction related to help-seeking, which consisted of explicit, declarative instruction about how to use the tutor effectively. For example, the teacher in the classroom reminded students “You will not learn by guessing or abusing hints, even if you get the answer right” (Roll et al., 2007, p. 206). The results of this study showed that the declarative instruction on help-seeking, the self-assessment and the help tutor did not result in higher levels of domain knowledge or higher levels of help-seeking behavior. However, students who were in the help tutor condition did develop significantly higher levels of declarative knowledge related to help-seeking.

Roll et al. (2007) provided several possible explanations for these results. One idea is that elaborated hints are not helpful when self-explanation is required. Another is that the researchers’ understanding of maladaptive help-seeking behavior may be inaccurate given that students who seek the bottom-out hint (initially considered a maladaptive metacognitive behavior) actually learn as much as those who do not. So the idea of progressive hints
may be faulty—it may be better for students to learn from solved or worked out examples. Finally, the authors conjecture that the unfamiliarity of the tutor environment may lead to lower levels of student motivation to use the hint system, or that the benefit of not looking at hints is greater from a time perspective and a short-term small gains approach than a long-term benefits approach. Another important idea to consider is how effective fixed and adaptive scaffolds may work together to improve student learning. For example, in a math-based classroom that is utilizing the algebra and/or geometry tutor, considering how either a programmable multi-agent system, or a public, peer-based, reflective assessment class activity may improve learning seems worthwhile; particularly due to the fact that these methods have proven quite powerful in the domain of science inquiry (White & Frederiksen, 1998, 2005).

In conclusion, research on metacognition and computers has focused on investigating the connection between metacognition and the learning of complex topics in CBLEs, as well as investigating methods and means of scaffolding metacognitive understanding in CBLEs. The first research focus clearly established that adaptive scaffolds provided by human tutors in are superior to computer-based fixed scaffolds. However, computer-based, fixed scaffolds are effective in some instances, for example when prompting self-questioning. More specifically, computer-based fixed scaffolds may be an effective complement to a holistic system of metacognitive learning that includes both human- and computer-based adaptive scaffolds. Furthermore, researchers have established innovative methods for creating computer-based adaptive scaffolds including allowing students to program metacognitive agents, providing customized scaffolds based on learners' website navigation patterns and through the development of computer-based tutor systems that work together to address student needs. Although promising, this research has shown that we still know little about how to create the adaptive scaffolds that will be useful to students in every setting. It is unlikely that the type of adaptive scaffolding that can be provided by a human tutor will be provided by a CBLE anytime soon. However, future research that examines more closely the metacognitive scaffolding provided by effective teachers would seem to hold much promise for designing and developing adaptive scaffolds that respond to student needs in real-time. Furthermore, future research should also focus on creating a deeper understanding of the emergent and strategic methods that students develop, which exceed the intention of the designs we provide them.

CONCLUSION: FUTURE RESEARCH ON METACOGNITION

We are encouraged by the promising future of metacognitive research, as researchers working from various disciplines begin to integrate theoretical frameworks and research methodologies, perhaps creating emergent models incorporating the varied theoretical perspectives. For example, cognitive scientists, neuropsychologists and clinicians, who have traditionally focused on deficits in executive function, are beginning to use their brain-based methods to examine executive function in normal populations. Cognitive psychologists, who have traditionally employed calibration techniques to study metacognition in controlled learning situations, are beginning to seek more applications of their work to classroom contexts and to use mixed method designs augmenting quantitative data with qualitative analyses (Carroll, 2008; Hacker, Bol, & Keener, 2008). Developmental and educational psychologists, evolving from the traditional approaches to metacognition and self-regulation, are becoming more familiar with the work of their European colleagues, particularly since the launching of an interdisciplinary, international journal focused on metacognition called Metacognition and Learning (published by Sage) in 2006. Researchers are explicitly pursuing connections between classroom and laboratory based research—from both sides of the research continuum and with a global perspective.

We have made tremendous progress in developing effective instructional methods to promote the development of metacognitive knowledge and skills and have identified a number of instructional methods that are effective in a variety of academic domains. Computer-based learning environments encouraging metacognitive development, with the potential to adapt flexibly and sensitively to the instructional needs of individual students, have been designed. We are learning more about how teachers can promote and support the development of metacognition in themselves and their students. Because metacognitive instruction appears to be linked to effective learning and subsequent academic achievement, these educational interventions have the potential to reduce long identified achievement gaps. We envision a future where effective interventions for the development of academic skills in students are widely used in elementary and secondary school classrooms, incorporated into summer transition programs and into first-year experiences, with the end result of ensuring a successful transition to college and enhancing college retention. The ultimate result of this
work is significant, ultimately realizing the promise of access and equity and allowing more students to pursue their dreams and achieve their potential.

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