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Self-Regulation and Mathematics Instruction

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Abstract. *The purpose of this article is to provide an overview of research-based interventions that incorporate self-regulation strategies to improve mathematics performance of students with learning disabilities (LD). Self-regulation is a metacognitive function essential to academic success. Students with LD are notoriously poor at self-regulation and must be taught explicitly to monitor and control their cognitive activities as they engage in academic tasks such as mathematical problem solving. This article describes intervention studies that use self-regulation strategies to improve mathematics performance of students with LD at the elementary, middle, and secondary school levels. Several techniques to facilitate effective implementation of self-regulation instruction in the classroom are presented.*

Over the past 10 years, researchers have begun to take a closer look at mathematics learning disabilities (MLD). Geary (2004) estimated the prevalence of MLD at between 5 percent and 8 percent of the school-age population, similar to the estimated prevalence of reading disabilities. However, unlike reading, poor achievement in mathematics actually may worsen as children progress through school due to the uniqueness of mathematics development. Mathematics is unique in that learners must acquire and apply a wide variety of different concepts and skills to be successful across the multiple branches in mathematics (e.g., algebra, geometry). Additionally, for most of these topics, learning is cumulative; in other words, new math skills and applications depend on mastery of previous concepts and skills.

Although the nature of mathematics learning and mathematics disabilities remains under investigation, there is substantial evidence accruing that cognitive mechanisms, particularly memory and monitoring processes, influence mathematical learning from early on (Swanson & Jerman, 2006). Students with LD characteristically display significant memory, attention, and self-regulation problems, which seem to adversely affect their performance in reading and/or mathematics (Swanson & Sáez, 2003). These characteristics underlie poor problem solving and strategic/self-regulated learning (Montague & Applegate, 1993a; Montague & Applegate, 1993b; Swanson & Jerman, 2006). Students with LD typically have a limited repertoire of strategies, immature metacognitive abilities, low motivation, and generally fail to monitor their academic performance by spontaneously detecting and correcting errors.

The overarching question is how do we effectively address these critical needs of students in the context of mathematics instruction? Fortunately, researchers have been conducting intervention research for the past 25 years to identify the most effective instructional practices to address the myriad characteristics of students with LD. Swanson's (1999) meta-analysis of intervention studies in LD across domains found cognitive strategy instruction and direct instruction, approaches that have many commonalities, to be the most powerful interventions for students with LD. Cognitive strategy instruction utilizes principles derived from memory research (Swanson, Cooney, & O'Shaughnessy, 1998) and research in verbal self-instruction, originating with Bandura, Gusec, and Menlove (1966) and Meichenbaum (1977). This approach focuses on teaching students the process of learning and can be used across domains, including mathematics (e.g., Montague, 2003). The instructional method underlying cognitive strategy instruction is explicit instruction, which incorporates numerous research-based practices and procedures such as cueing, modeling, verbal rehearsal, and feedback. Instruction is highly structured and organized with appropriate cues and prompts built in, leading to mastery of new concepts, skills, and applications and eventual automaticity of responses. In essence, students learn to think and behave like proficient learners as they apply various cognitive processes and self-regulation strategies. To illustrate, for mathematical problem solving, students learn to read, analyze, evaluate, and verify math problems using comprehension processes such as paraphrasing, visualization, and planning as well as self-regulation strategies including self-instruction, self-questioning, and self-checking (Montague, 2006).

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Self-regulation enhances learning by helping students to take control of their actions and move toward independence as they learn. Self-regulation can take the form of simple self-monitoring techniques such as a tally sheet to record whether or not the student is attending to the task, or it can be a component of a comprehensive routine for solving complex mathematical problems. In their meta-analysis of mathematics interventions for elementary school children with special educational needs, Kroesbergen and Van Luit (2003) concluded that self-instruction, a self-regulation strategy, is the most effective method for teaching math problem solving; direct instruction is most effective for teaching basic skills; and both are superior to mediated/assisted instruction (e.g., peer tutoring or computer-assisted instruction) for teaching mathematics generally. Intervention research that supports self-regulation instruction in mathematics for students with LD in elementary, middle, and secondary school is described below. While the research is limited and most of the studies were single-subject designs, typically multiple baseline designs, they do offer promise for understanding how self-regulation as a component of instruction can improve teaching and learning for students with MLD.

Self-Regulation Interventions for Elementary School Mathematics

Self-monitoring has been used to improve performance in math computation for students with MLD. This technique involves teaching students to use a systematic procedure for assessing whether or not a target behavior has occurred and recording the occurrence in some way, for example, by counting the number of problems completed and recording that number on an individual checklist or graph (Reid, 1996). Two types of self-monitoring have been used. The type most commonly studied is self-monitoring of attention, which teaches students to assess whether or not they are attending to the task and to record the results when cued to do so, often using a tape that sounds a tone at various intervals. The second type is performance self-monitoring, which teaches students to assess some aspect of academic performance such as productivity (e.g., the number of math problems completed); accuracy (e.g., the number of math problems completed correctly); or strategy use (e.g., whether all steps in a particular strategy were completed) and then record the results pertaining to performance. The following two studies exemplify this approach.

Maag, Reid, and DiGangi (1993) studied the effects of self-monitoring on attention to task, productivity, and accuracy using math computation tasks with six elementary school students with LD in general education classrooms. Students were trained and alerted to the specific self-monitoring goal. A taped tone was used to cue students to record results for on-task behavior, number of problems completed, or number of problems completed correctly. Results indicated no specific pattern for on-task behavior. However, productivity self-monitoring increased the number of problems completed and also accuracy for fourth graders. For sixth graders, it increased only the number of problems completed; however, accuracy self-monitoring increased accuracy of responses. Dunlap and Dunlap (1989) also studied a self-monitoring package consisting of individualized self-monitoring checklists based on the types of errors three students with LD made on subtraction computation problems. For example, one student checked off the following statements based on his individualized error analysis.

1. I copied the problem correctly.
2. I regrouped when I needed to (top number is bigger than the bottom).
3. I borrowed correctly (number crossed out is one bigger).
4. I subtracted all the numbers.
5. I subtracted correctly.

All students improved dramatically and maintained performance levels when the self-monitoring checklist was replaced by a reward system, suggesting that students did learn a system for detecting and correcting their errors in subtraction.

Self-instruction is a form of verbal mediation designed to help students focus attention, cue themselves to perform a specific behavior, and successfully complete tasks. This technique has been applied to both mathematics computation and problem solving. In one study, three students with MLD in elementary student school received self-instruction training, then tape-recorded the instructions in their own voice, and finally used the recording to complete math computation tasks, each consisting of 20 addition and subtraction computations (Wood, Rosenberg, & Carran, 1993). Students completed more problems and improved in accuracy following the intervention. Self-instruction was the foundation for a comprehensive program for improving students' multiplication and division skills (Van Luit & Naglieri, 1999). Participants in this study included 42 elementary school students with LD. Results indicated a significant improvement compared with the general instructional program. The students with LD generalized the self-instruction procedure to more difficult problems. Focusing on math problem solving, Owen and Fuchs (2002) examined the effects of self-instruction on math problems that required students with MLD to find half of a particular number. Compared with a control group, the students who received the entire intervention improved in both number of problems solved and accuracy of those solved.

Two models of strategy instruction, each with a built-in self-regulation component, have been tested with elementary school students with LD to improve performance in mathematical problem solving. The first model, Self-Regulated Strategy Development, investigated in two different single-subject studies (Case, Harris, & Graham, 1992; Cassel & Reid, 1996) involves the application of a seven-stage self-regulated strategy intervention (Harris & Graham, 1993). This intervention model emphasizes teaching prerequisite skills needed to use the strategy and explicit instruction in applying the strategy when solving addition and subtraction word problems. The self-regulation component consists of procedures for self-assessment, self-recording, and self-instruction. The stages of the intervention included the following:

1. Conferencing regarding baseline performance level and obtaining a commitment to learn from the student.
2. Discussion of the problem-solving strategy.
3. Modeling of the strategy steps and self-instructions.
4. Mastery of the strategy steps.
5. Collaborative practice using the strategy to solve math problems.
6. Independent practice using the strategy to solve math problems.
7. Generalization and maintenance components.

To help students remember the strategy steps, a mnemonic was developed and self-statements were incorporated. Students were instructed to read the problem aloud, find and highlight the question and write the label, set up the problem by writing and labeling the numbers, reread the problem and identify the correct algorithm to solve the problem, write the number problem and mathematical sign for the algorithm, read the number problem, do the computation, write the answer, and check the computation. A self-monitoring checklist, which contained the self-statements associated with each strategy step, was used initially and then withdrawn as students became facile using the strategy. All students reached mastery in using the strategy to solve problems, became more accurate in solving problems, and generalized the strategy to another setting. Maintenance effects were mixed, suggesting the need for distributed practice to maintain strategy use and improved math problem-solving performance over time.

The second model, Schema-Based Strategy Instruction, was investigated in two studies involving elementary school students in grades two through five (Jitendra & Hoff, 1996; Jitendra et al., 1998). The basis of this approach is the idea that students can develop schemas for certain problem types. For example, the following problem represents one type of the *compare* problem schema: "Jack has 56 baseball cards. His friend, Eddie, has 85." This could be either a "more than" or "less than" problem. A diagram is used to represent the relationship, and students learn to recognize the problem schema and complete the schematic diagram to solve the problem. Thus, during the problem schema instruction phase, teaching focuses on identifying the problem structure using problems with no unknowns, that is, a complete representation of the problem. Then, problem solution instruction is introduced. In this phase, students learn how to solve problems with unknowns. A four-step self-monitoring checklist, the self-regulation component of this strategic approach to problem solving, is provided to guide students through the problem-solving process. Each directive is followed by questions that students answer to monitor their performance. To illustrate, for Step 1: Find the problem type, students ask themselves, "Did I read and retell the problem to ask if it is a subtraction compare problem? Did I look for the subtraction compare words, such as 'how many more than x does y have'?" and so forth.

Students with LD in both studies improved in problem solving, and in one of the studies (Jitendra et al., 1998), students outperformed the group who received the traditional basal instruction. Maintenance and generalization effects were found in both studies.

In sum, elementary school students with LD can be taught how to use self-regulation techniques to improve their mathematics performance. These techniques can be implemented easily by teachers in the special or general education classroom to improve both computation and problem solving. Self-regulation, that is, self-assessment, self-recording, and self-instruction, has been effective for improving both computation and word problem solving. A simple self-instructional checklist, like those described earlier, can serve as a reminder for students as they complete addition, subtraction, multiplication, and division algorithms. Research has established that simple self-recording checklists can help students focus on completing computation problems and completing them more accurately. It is important, however, to consider the individual needs of youngsters (e.g., the thresholds of individual students). To illustrate, Sara, a first-grade student, has difficulty sustaining attention and generally completes only one or two addition and subtraction problems independently, and often these are incorrect. When the self-recording checklist is introduced, she is able to focus not only on completing more problems, but also completing them accurately. The performance goal for Sara may start with completing 5 problems correctly and, when that goal is met, the criterion can be increased to 7 problems and, eventually, to 10 problems, which the teacher recognizes as Sara's threshold. In contrast, for problem solving, self-regulation is one component of a comprehensive instructional routine. For example, Jitendra et al. (1998), in their schema-based instructional routine, taught students a generalizable rule based on a part-whole concept for deciding which operation to use to solve the problem: "When the total (whole) is not known, we add to find the total. When the total is known, we subtract to find the other (part) amount." In this way, students use self-instruction to understand the relationship of the problem elements in the final phase of problem solving.

Self-Regulation Interventions for Middle School Mathematics

Five studies employing self-regulation strategies as a component of strategy instruction were located. See Montague and Jitendra (2006) for a more detailed explanation of the problem-solving models. Jitendra's model, Schema-Based Strategy Instruction, was the intervention for two single-subject studies and one group study (Jitendra, DiPippi, & Perron-Jones, 2002; Jitendra, Hoff, & Beck, 1999; Xin, Jitendra, & Beatline-Buchman, 2005). All students improved in solving multiplication and division word problems. Maintenance of strategy use and performance level varied between 2 and 10 weeks, and there was evidence of generalization of strategy use to novel problems.

Montague's *Solve It!* curriculum was the intervention for two studies, a single-subject and a group study (Montague, 1992; Montague, Applegate, & Marquard, 1993). The sixth-grade students in the single-subject study did not reach criterion for mastery, indicating that adaptations may be needed for younger students. Older students improved substantially, and in the group study, following intervention, performed at the same level as average-achieving peers on a measure of math problem solving. For middle school students, it appears that self-regulation strategies as a component of cognitive strategy instruction help to give students the cognitive and metacognitive tools to take control of their actions, make appropriate decisions, and independently solve problems.

Jitendra's model, as described in the last section, has been successfully used to teach elementary school students to solve various types of addition and subtraction problems. In her middle school studies, students were taught the schemata for multiplication and division problems, that is, the multiplicative compare problem schema and the proportion problem schema. To illustrate, for problems like the following: Juan earned \$15 raking leaves. This was one-third as much as Jennifer made. How much did Jennifer earn?, students were taught that a multiplicative compare problem always includes a referent set, a compared set, and a statement that relates the compared set to the referent set. In this problem, the compared set is \$15, one-third is the relation, and the referent set is unknown. See Figure 1 for an illustration of the schema diagram. Again, a four-step strategy is taught. Prompt sheets are provided initially and then faded as students learn to recognize the schema and apply the strategy. The first strategy step requires students to identify and underline the relational statement in the problem. The second step requires students to identify the referent (unknown) and the compared set and then map the information onto the provided schema diagram. Step three entails transforming the information in the diagram into a math equation (in this example, "\$15 over ? equals one-third."). The fourth and final step has students compute, write the answer, and check the accuracy of the diagrammatic representation and the computation. Figure 2 presents a four-step prompt sheet for a "vary" problem.

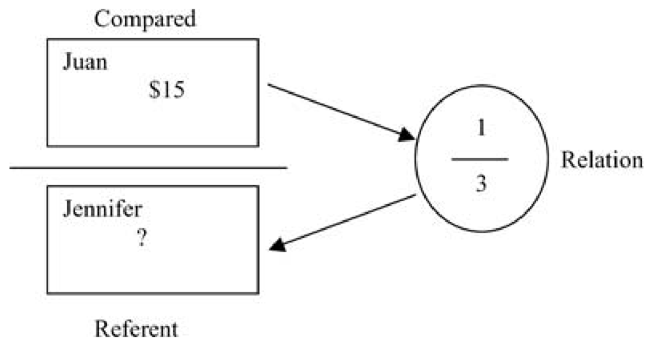

FIGURE 1
Schema for a multiplicative compare problem.

In Montague's model, students are taught to self-instruct or tell themselves what to do, self-question or ask themselves questions as they solve problems, and self-monitor or check themselves throughout the problem-solving process. Self-instruction involves providing one's own prompts and talking oneself through the problem-solving routine. Some students have difficulty using self-instruction because they have had little practice verbalizing what they do and remembering sequences of behaviors or activities. Self-instruction combined with self-questioning is very effective for guiding learners through the problem-solving process. Self-questioning is a form of cognitive cueing that helps students remember to use certain processes, skills, and behaviors. Students are taught the appropriate questions to ask and are provided ample practice in asking the questions as they solve problems. For example, after formulating a visual representation of the problem, they should ask themselves, "Did the picture fit the problem? Did I show the relationships among the problem parts?" Self-checking helps students review and reflect on the problem and ensure that the solution path is appropriate and correct as well as check the procedures and computations for mistakes. Each phase and process of the problem-solving routine has a corresponding self-regulation strategy (a SAY, ASK, CHECK procedure). That is, students learn to check that they understand the problem, check that the information selected is correct and makes sense, check that the schematic representation reflects the problem information and shows the relationships among the problem parts, check that the solution plan is appropriate, check that they used all the important information, check that the operations were completed in the correct sequence, and finally, check that the answer is correct. To do this, the following routine is used (see Figure 3). If they are unsure at any time as they solve the problem, they tell themselves to return to the problem to recheck or ask for help. Students are taught how to decide if they need help, whom to ask, and how to ask for help.

Step 1. **F**ind the problem type

- [ ] Did I read and retell the problem to ask if it is a *vary* problem? (Did I look for a "rate" or "ratio" type of association between two dimensions? Does the problem involve an "if…then" kind of statement that makes up two pairs of associations?)

Step 2. **O**rganize the information using the *vary* diagram

- [ ] Did I write the labels for the two dimensions in the diagram?
- [ ] Did I write the numbers given for the two pairs of associations in the diagram?
- [ ] Did I write a "?" for the missing number?

Step 3. **P**lan to solve the problem

- [ ] Did I transform the information in the diagram into a math sentence or an equation?

Step 4. **S**olve the problem

- [ ] Did I solve for the missing number in the math sentence or equation?
- [ ] Did I write the complete answer?
- [ ] Did I check if the answer makes sense?

FIGURE 2
Self-monitoring checklist for solving vary problems.

Scripted lessons with proven procedures associated with explicit instruction provided the teaching/learning structure. These procedures, incorporated into the scripts, include verbal rehearsal, process modeling, visualization, performance feedback, mastery learning, and distributed practice. When students initially learn a strategy, they must first memorize a sequence of activities for the cognitive routine. Students are cued and prompted until they can recite the salient steps of the strategy from memory. Sometimes acronyms are used to remind students of the sequence. For example, RPV-HECC (read, paraphrase, visualization, hypothesize, estimate, compute, check) helps students remember the cognitive processes taught with *Solve It*!. Process modeling is simply thinking aloud or saying everything one is thinking and doing while solving problems. First, the teachers model use of the strategy, solving actual problems. As students become familiar with the routine, they can exchange roles with the teacher and model the problem-solving process for other students. Visualization, critical to understanding the problem, is a problem-representation process. Students learn how to construct a schematic or relational image of the problem, either mentally or in writing. Positive and corrective feedback is provided by teachers and peers throughout the acquisition and application phases of instruction. Mastery learning implies meeting a preset performance criterion, for example, 7 problems correct out of 10 over four consecutive tests of 10 one-, two-, and three-step problems. Distributed practice is necessary if students are to maintain use of the strategy and the requisite performance level.

In sum, self-regulation, as a component of instructional routines for solving mathematical problems, has been effective for teaching students how strategic, self-regulated learners solve problems. Compared with self-regulation techniques used by elementary school students with LD, the techniques

Math Problem Solving Processes and Strategies

READ (for understanding)
Say: Read the problem. If I don't understand, read it again.
Ask: Have I read and understood the problem?
Check: For understanding as I solve the problem.

PARAPHRASE (your own words)
Say: Underline the important information. Put the problem in my own words.
Ask: Have I underlined the important information? What is the question? What am I looking for?
Check: That the information goes with the question.

VISUALIZE (a picture or a diagram)
Say: Make a drawing or a diagram. Show the relationships among the problem parts.
Ask: Does the picture fit the problem? Did I show the relationships?
Check: The picture against the problem information.

HYPOTHESIZE (a plan to solve the problem)
Say: Decide how many steps and operations are needed. Write the operation symbols (+, −, ×, and /).
Ask: If I …, what will I get? If I …, then what do I need to do next? How many steps are needed?
Check: That the plan makes sense.

ESTIMATE (predict the answer)
Say: Round the numbers, do the problem in my head, and write the estimate.
Ask: Did I round up and down? Did I write the estimate?
Check: That I used the important information.

COMPUTE (do the arithmetic)
Say: Do the operations in the right order.
Ask: How does my answer compare with my estimate? Does my answer make sense? Are the decimals or money signs in the right places?
Check: That all the operations were done in the right order.

CHECK (make sure everything is right)
Say: Check the plan to make sure it is right. Check the computation.
Ask: Have I checked every step? Have I checked the computation? Is my answer right?
Check: That everything is right. If not, go back. Ask for help if I need it.

FIGURE 3
Math problem-solving processes and strategies.

used in the studies with middle school students are more complex and comprehensive. In these studies, students learned to monitor their problem-solving performance by using a variety of self-regulation activities (i.e., self-assessment, self-instruction, self-questioning, and self-evaluation). The ultimate goal of instruction is that students will acquire and internalize these processes and strategies and apply them automatically when they become competent mathematical problem solvers.

Self-Regulation Interventions for Secondary School Mathematics

Four studies of mathematical problem solving that included a self-regulation component were found (Hutchinson, 1993; Maccini & Hughes, 2000; Maccini & Ruhl, 2000; Montague & Bos, 1986). Montague's *Solve It!* model, described in the previous section, was the intervention in a study with six secondary school students with MLD (Montague & Bos, 1986).

Self-Questions for Representing Algebra Word Problems

1. Have I read and understood each sentence? Are there any words whose meaning I have to ask.
2. Have I got the whole picture, a representation, for the problem?
3. Have I written down my representation on the worksheet? (goal, unknown(s), known(s), type of problem, equation
4. What should I look for in a new problem to see it is the same kind of problem?

Self-Questions for Solving Algebra Word Problems

1. Have I written an equation?
2. Have I expanded the terms?
3. Have I written out the steps of my solution on the worksheet? (collected like terms, isolated unknown(s), solved for unknown(s), checked my answer with the goal, highlighted my answer)
4. What should I look for in a new problem to see if it is the same kind of problem?

FIGURE 4
Self-question prompt card for solving algebra problems.

All students improved to criterion, maintained the strategy and performance level over time, and generalized strategy use to more difficult problems.

Maccini's and Hutchinson's models focus on strategies for teaching secondary students how to solve algebraic problems. Maccini's model is an instructional strategy using a graduated teaching sequence moving from the concrete to semiconcrete to abstract representations and solutions with problems involving addition, subtraction, multiplication, and division of integers (Maccini & Hughes, 2000; Maccini & Ruhl, 2000). Her "STAR" strategy utilizes manipulatives and a systematic sequence of steps:

S = Search the word problem (Read; Ask yourself questions, i.e., What facts do I know? What do I need to find?; Write down facts).
T = Translate the words into an equation in picture form (Choose a variable; Identify the operations; Represent the problem using concrete, semi-concrete, and abstract representations).
A = Answer the problem using cues and a work mat.
R = Review the solution (Reread the problem; Ask the question, i.e., Does the answer make sense? Why? Check the answer).

In both studies, students with LD improved their ability to represent algebraic problems and to accurately solve word problems. They also maintained improved performance over time and generalized strategy use.

Hutchinson (1993) used a more traditional cognitive strategy instructional approach that included a set of self-questions on prompt cards for the problem representation and solution phases listed below and a structured worksheet (see Figures 4 and 5). Hutchinson taught three types of algebra problems: relational problems (e.g., Eddie walks 6 miles farther than Amelia. If the total distance walked by both is 32 miles, how far did each walk?), proportion problems (e.g., On a map, a distance of 2 inches represents 120 miles. What distance is represented on this map by 5 inches?), and two-variable two-equation problems (e.g., Sam traveled 760 miles, some at 80 miles per hour and some at 60 miles per hour. The total time taken was 8 hours. Find the distance Sam traveled at 80 miles per hour). Like typical cognitive strategy intervention research, scripted lessons were developed to guide instruction. The students with LD who received instruction outperformed the comparison group of peers with LD on the posttest consisting of five problems of each type, and maintenance and transfer of the strategy were evident.

The studies involving self-regulation as a component embedded in instructional routines to improve math problem solving for secondary students differ from the middle school studies only in the difficulty level of the math problems. While Montague's study focused on typical general mathematics textbook problems, Maccini's and Hutchinson's focused on improving algebra problem solving (Hutchinson, 1993; Maccini & Hughes, 2000; Maccini & Ruhl, 2000). Maccini used a general strategy that emphasized moving from concrete to semiconcrete to abstract representations of the problems, whereas Hutchinson focused on teaching students to differentiate among common algebra problem types, much like the schema-based instructional method of Jitendra (e.g., Jitendra, DiPippi, & Perron-Jones, 2002).

CONCLUSION

Students with LD are characteristically poor self-regulators and thus need explicit instruction in self-regulation to be successful across academic domains. Self-regulation includes but is not limited to

Goal: ____

What I don't know: ______________________________________

What I know:

I can write/say this problem in my own words. Draw a picture.

Kind of problem: _______________________________________

Equation:

Solving the equation:

Solution:

Compare to goal:

Check:

FIGURE 5
Structured worksheet for solving algebra problems.

self-assessment and evaluation, self-instruction, self-questioning, self-monitoring, self-correction, and self-reinforcement. The ability to regulate one's strategy use and performance is critical to academic success. Interventions like those described in this article should provide the opportunity for students to become better self-regulators and more proficient in mathematics. For effective implementation, the following instructional techniques are recommended.

- Model the use of self-regulation strategies in the context of the math activity.
- Have students verbally rehearse self-regulation strategies before they begin to apply them.
- Provide self-recording cards, cue cards, or prompt sheets to remind students of the instructions or questions they need to use as they complete the task.
- Have students self-regulate aloud until they become comfortable with the routine and are successful in completing the task accurately.
- Provide a visual record of success (e.g., a graph to document improvement over time).
- Fade cues and prompts as students become more competent in using self-regulation.

As students become more proficient in mathematics, their attitude toward mathematics and their academic self-concept improve (e.g., Montague, 1992). As students become more competent and feel better about their math performance, they gain more confidence and become more motivated to persevere, which increases their chances of success. Mathematical proficiency is essential not only to success in school, but also to success in adult life.

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