Mathematics Instruction and PASS Cognitive Processes: An Intervention Study

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Abstract

The purpose of this study was to determine if an instruction designed to facilitate planning, given by teachers to their class as a group, would have differential effects depending on the specific cognitive characteristics of the individual students. A cognitive instruction that facilitated planning was provided to a group of 12 students with learning disabilities. All students completed math work sheets during 7 sessions of baseline and 21 sessions of intervention (when the instruction designed to facilitate planning was provided). During the intervention phase, students engaged in self-reflection and verbalization of strategies about how mathematics problems were completed. The class was sorted according to planning scores, obtained using the Cognitive Assessment System, which is based on Planning, Attention, Simultaneous, Successive (PASS) theory; and low- and high-planning contrast groups were identified. The results, consistent with previous research, showed that teaching control and regulation of cognitive activity had beneficial effects for all students but was especially helpful for those who were poor in planning, as defined by the PASS theory. Implications of these findings are provided.

Students with learning difficulties in math typically "achieve approximately one year of academic growth for each two years of schooling" (Scheid, 1993, p. 13), because they lack proficiency in the procedures required for success, as well as basic arithmetic facts. The effective use of problem-solving strategies is particularly problematic for students with learning difficulties (Das, Naglieri, & Kirby, 1994) and especially important in mathematics, where careful analysis and systematic execution of procedures is required. To facilitate student performance in mathematics, both content area instruction and cognitive strategy instruction are recommended (Conway & Ashman, 1989; Ellis, 1993; Scheid, 1993). That is, at the root of this perspective is the assumption that efficient cognitive processes, as well as knowledge of curriculum, are important for maximizing learning.

Assuming that learning problems can be the result of weaknesses in achievement and cognitive processing (Kirby & Williams, 1991), a thorough picture of an individual's cognitive competence and academic knowledge is helpful when selecting or applying educational methods (Das et al., 1994). To design an appropriate academic instruction that meets the student's cognitive needs, professionals require a complete and accurate picture of a person's level of cognitive processing in specific areas (Kirby & Williams, 1991). Although psychologists and educators have attempted to use intelligence tests for this purpose, they have had limited success (Das et al., 1994), suggesting that some alternative is needed. Recently, researchers have argued that a theoretical view that goes beyond general intelligence is needed if a student's competence in the basic cognitive processes is to be used to guide intervention (Kirby & Williams, 1991; Naglieri & Das, 1990; Snow, 1989). One such alternative theoretical view of human cognitive functioning is described as Planning, Attention, Simultaneous, and Successive (PASS; Das et al., 1994; Naglieri & Das, 1990).

The PASS Theory

The PASS theory was described by Das et al. (1994) as a modern view of intelligence following Luria's (1966, 1970, 1973, 1974, 1980) analyses of the cognitive processes associated with various brain structures. Luria described human cognitive processes with the framework of three functional units: (a) cortical arousal and attention; (b) simultaneous and successive information processes; and (c) planning, self-monitoring, and structuring of cognitive activities. Luria's work on the functional aspects of the brain formed the underlying structure of the PASS theory and was used as a blueprint for defining the four important cognitive processes. Because thorough summaries of the PASS theory and related research are presented elsewhere (Das, Kirby, & Jarman, 1979; Das et al., 1994; Naglieri, 1989; Naglieri & Das, 1990; Naglieri, Das, & Jarman, 1990), only a brief summary is provided here.

PASS Processes

Planning processes provide for the programming, regulation, and verification of behavior and are responsible for behavior such as asking questions, problem solving, and self-monitoring (Luria, 1973) . Other functions involving planning include regulation of voluntary activity, impulse control, and various linguistic skills, such as spontaneous conversation. According to Naglieri and Das (1997a), planning provides an individual with the means to solve a problem for which no method of solution is apparent. It may be a complex or simple task and may involve attentional, simultaneous, or successive processes, but the main requirement is to determine how to solve the problem. Once the need for a plan is apparent, the person might try to recall a particular approach. If one is not within his or her knowledge base, an initial plan of action might be developed and the plan examined to determine if it is reasonable. If it is acceptable, the plan is carried out; if it is not, a new plan is devised. If the plan is put into action, decisions are made regarding whether to continue applying it as is, modify it to achieve the most efficient approach to problem solving, or generate a new approach. This process involves the most complex aspects of human behavior (Das, 1984) and an overall means by which activity is governed.

Attentional processes provide an appropriate level of arousal or cortical tone and "directive and selective attention" (Luria, 1973, p. 273), including more complex forms of attention involving "selective recognition of a particular stimulus and inhibition of responses to irrelevant stimuli" (Luria, 1973, p. 271). Attentional processes are called upon when a multidimensional stimulus array is presented and the task requires selective attention to one dimension and inhibition of distracting stimuli.

Simultaneous and successive processes are the "two basic forms of integrative activity of the cerebral cortex" (Luria, 1966, p. 74) responsible for "receiving, analyzing and storing information" (Luria, 1973, p. 67). Simultaneous processing is associated with the occipital–parietal areas of the brain (Luria, 1973) and involves the integration of stimuli into interrelated stimulus arrays (Luria, 1966). The essential aspect of simultaneous processing is that all elements are related to every other (Naglieri, 1989). Successive processing involves the integration of stimuli into a specific serial order (Luria, 1966), whereby each dimension of the entire stimulus is related only to the next. That is, in successive synthesis, "each link integrated into a series can evoke only a particular chain of successive links following each other in serial order" (Luria, 1966, p. 77).

PASS Theory and Instruction

There exists a series of studies that illustrate the implications that planning processes have for instruction. In each of these investigations, students who had poor scores on measures of planning improved more than those who had high scores in planning when given the same instruction designed to facilitate planfulness. This was first shown by Cormier, Carlson, and Das (1990), who instructed students to solve progressive matrices while verbalizing the problem, then justify their choice, and, finally, explain why each of the other options was not correct. They found that, after this instruction, which encouraged careful analysis of the problem, self-monitoring, and self-correction, students who had performed poorly on measures of planning earned significantly higher scores than those with good scores on planning measures. The instruction facilitated a planful and organized examination of the component parts of the task and analysis of the relevant information (good planning) for those that needed to do this the most (those with low planning scores).

A second examination of the effects of this technique was provided by Kar, Dash, Das, and Carlson (1992). They conducted two experiments that examined the extent to which students with good and poor scores on measures of planning differentially benefited from instruction designed to facilitate the use of strategies involving a verbalization technique such as that used by Cormier et al. (1990). Their two experiments showed that encouraging strategy verbalization was more effective for those with low planning scores than those with higher planning scores. They argued that the use and content of the verbalizations engaged planning processes for children who otherwise would not adequately utilize this process. Although the results of these two studies suggest that providing instruction that facilitated planning improved the performance of students with low planning scores, neither involved academic tasks, such as math.

Using academic content (mathematics) taken directly from the class curriculum, Naglieri and Gottling (1995) conducted a study that examined the possible differential effects of instruction designed to facilitate planfulness. They extended the research by Cormier et al. (1990) and Kar et al. (1992) by using a similar method of individual tutoring sessions designed to facilitate planning. The results of their study showed that the intervention helped those with low scores in planning considerably more than those with high planning scores on multiplication problems. This study was the first to examine the usefulness of training in planning processes as part of mathematics instruction for students with learning disabilities who had low versus average scores on planning. Because these results suggested that students benefited differentially from the instruction depending on their cognitive processing abilities, matching the instruction to the child's cognitive weakness (or strength) was again suggested. Because this was the first study of its kind, however, further research is clearly needed to determine the extent to which these results could be replicated, and whether they would be found under different conditions.

The purposes of the present investigation were to (a) attempt to replicate Naglieri and Gottling's (1995) study; (b) extend the technique utilized by Cormier et al. (1990), Kar et al., (1992), and Naglieri and Gottling to a group instructional setting; (c) have instruction delivered by the general classroom teacher rather than a special tutor; (d) conduct the intervention over a longer period of time to allow for the examination of the trajectory of change; and, most importantly, (e) assess whether a student's math performance would be differentially affected by treatment designed to facilitate planning on the basis of his or her planning scores. It was expected that students with poor planning scores would improve more than those with high planning scores, because the former group's need to be more planful would be met by the instruction.

Method

Participants

The sample was composed of 12 students (6 girls and 6 boys; 24% minority) who ranged in age from 9 years 2 months through 12 years 4 months (mean = 10 years 10 months). All students came from two math classes from the lower division (Grades 1 through 6) who attended a private school that specializes in the treatment of students with significant learning problems. All students attended the private school because they had made minimal educational progress in public special education programs. Criteria for diagnosis of a learning disability followed state of Ohio and federal guidelines, including average intelligence and a significant discrepancy between IQ and achievement.

Students were administered the standardization edition of the Cognitive Assessment System (CAS; Naglieri & Das, 1997b) to measure their level of competence in planning, attention, simultaneous, and successive processes. Two graduate students in school psychology, trained by the first author, administered the CAS in the usual manner. All testing was conducted at the start of the study, individually, in a private room, and in one session, but the results were not scored until the entire study was completed. Raw scores for each of the 12 subtests (three in each of the PASS areas) were obtained and converted to standard scores (mean = 100, *SD* = 15) using test norms. Raw scores were converted into standard scores via the normal procedure (Naglieri & Das, 1997b). These scores were intended to provide a way to rank each student in comparison to those included in this study rather than in relation to a national norm. Each student's three subtest scores in the PASS areas were used to obtain a PASS Scale score. These values were used to sort the sample into three groups (low, medium, and high) on the basis of scores on the planning measures.

After the entire study was completed, the sample of 12 was sorted according to participants' overall standard scores in planning to obtain two contrast groups with low and high planning scores. The low group had scores of 85 and below, and the high group had planning scores of 100 and above. The following mean PASS scores were obtained for the low and high contrast groups, respectively: Planning, 79.8 and 105.5; Attention, 86.5 and 98.5; Simultaneous, 83.8 and 93.3; and Successive, 81.8 and 86.5. The range of scores for the 4 students with low scores in planning was 75 to 82, and for the four with high scores, the range was 100 to 110. Thus, the students with low planning scores were about 1⅓ *SD* below the mean, and the contrast group was about ⅓ *SD* above the mean.

Teachers

Two experienced teachers who provide instruction to these students with learning disabilities on a regular basis participated in this study. They had no knowledge of the PASS scores of the students in their classes and minimal knowledge of the goals of the study (examination of differential effects of instruction). The teachers were instructed in an initial 1-hour session to have the students complete mathematics work sheets in a specific sequence of baseline and intervention sessions. Guidelines for prompting were also first provided in this initial session (see the Procedure section). During the time the experiment was under way, the authors met with the teachers weekly to assist in the execution of the study, monitor the progress of the project, and collaborate on ways of better facilitating classroom discussions (see the Procedure section for more details).

Materials

Pages of mathematics were created on the computer according to specifications for similar pages that had been used in the math class during the previous month. Subtraction work sheets contained 54 math problems presented in six rows and nine columns in a vertical format, with a minus sign to the left of the column of numbers and a line under the bottom row of numbers. There were six types of subtraction problems in each work sheet, involving numbers ranging in size from one to three digits (no decimals), with and without regrouping. The problems were placed in a random order by type of subtraction throughout the work sheet. Similarly, multiplication problems were written that involved whole numbers being multiplied by two-digit numbers that ranged from 10 to 99, with and without carrying. Multiplication problems were also presented in a vertical format with a multiplication sign to the left of the bottom row of numbers. A total of 28 work sheets of subtraction and 28 of multiplication (for the baseline and intervention phases) with the same specifications were obtained by recalculating the values in each spreadsheet using the random-number-generator option in the EXCEL 4.0 and 5.0 programs. The use of computer-generated items provided a control of difficulty, assured similarity of each work sheet on the basis of the structure of the problems, and still provided a diversity of items.

Procedure

The entire study was conducted in sessions that were organized into half-hour blocks of time. These half-hour blocks were conducted either two or three times a week (depending on the school schedule of classes, specials, etc.) over a period of 8 weeks. During the first 10 minutes of each session, students were given the math work sheet and instructed to get as many of the problems correct as they could. The second 10-minute period was used for general group discussion unrelated to the math work sheets during the baseline period, and for facilitating planning during the intervention phase. Following the 10-minute period of class discussion, another 10-minute working period was given. These sessions were conducted separately by each teacher for the students they regularly taught. To facilitate discussion, examples of the students' work sheets were presented (assuring confidentiality) to the class via an overhead projector. All math work sheets were scored by the second author, who also collaborated with the teachers to select pages that contained examples of the children's work that were suitable for stimulating discussion. For instance, one student had only partially completed the math on a work sheet (all the multiplication was completed but the final step of addition was not conducted for most of the problems). This page was shown to the group. The teacher then raised the question, "Can anyone tell me something about how the student did these problems?" to facilitate discussion.

Baseline. There were seven baseline sessions conducted prior to the intervention phase. All students were given 54 mathematics problems on work sheets and asked to solve as many as they could within a 10-minute period. The students were instructed to write their answers in the appropriate place under each problem.

Intervention. All students were exposed to the 21 sessions during the intervention phase of the study. In each of the intervention sessions, students attempted to solve the 54 mathematics problems presented in each work sheet within 10 minutes.

The self-reflection sessions were designed with both general and specific goals in mind. First, the self-reflection approach was designed to facilitate the child's recognition of the need to be planful and utilize an efficient strategy when completing the math problems. To help children achieve this general goal, the teachers encouraged them to (a) determine how they completed the work sheets, b) verbalize and discuss their ideas, (c) explain which methods worked well and which worked poorly; and (d) be self-reflective. To help children achieve the general goal of self-reflection, the teachers used the following probes:

Can anyone tell me anything about these problems?
Let's talk about how you did the work sheet.
Why did you do it that way?
How did you do the problems?
What could you have done to get more correct?
What did it teach you?
What else did you notice about how this page was done?
What will you do next time?
I noticed that many of you did not do what you said was important. What do you think of that?

In response to these probes, the students said things such as,

When I get distracted, I'll move my seat.
I have to remember to borrow.
I'll do all the easy ones first.
I do them row by row.
I do the ones with 1s, 0s, and 10s in them—they're easy.
If it's a big problem (all big numbers on the top), you don't have to borrow, so do it first.
I have to remember to add the numbers after multiplying.
I have to keep the columns straight.
Be sure to get them right, not just get them done.
I have to stay awake.

These probes were presented by the teachers to facilitate discussion, which was used to encourage the children to consider various ways to be more successful. When a student provided a response, this often became the beginning point for discussion and further development of the idea. During this time, however, the teacher made no statements such as "That is correct" or "Remember to use that same strategy," provided no feedback on the number correct, and never gave mathematics instruction.

Data Analyses. The number correct per page was calculated for each student's 28 math work sheets. For each child, the number of problems correct per work sheet was first averaged within the seven baseline sessions. The 21 intervention sessions were collapsed into three groups (Sessions 1 through 7, 8 through 14, and 15 through 21), and the mean number correct was calculated per seven-session segment. This aggregated the 28 sessions into four segments (one baseline and three intervention), each composed of seven sessions for each child. Individual student data were also calculated for the four segments. Next, contrast groups were identified on the basis of their PASS scores and were averaged across children for the four segments. For example, the sample of 12 children was sorted by planning scores and divided into three groups of equal size ($n = 4$ per group) to obtain samples of children with low, medium, and high scores. Those with low and high scores on PASS were used as contrast groups.

Two types of calculations were conducted, First, the number correct per segment was obtained, and, second, the percentage of change over baseline was calculated. The percentage of change was calculated for each child by subtracting each intervention segment mean from the child's mean baseline and then dividing the difference by the mean baseline. These values were then calculated individually for each student and averaged for the 4 children in each contrast group to obtain the mean number correct per segment and the percentage of change per contrast group.

Results

The mean number correct on the math work sheets and the percentage of change over baseline are presented for individual students in Table 1. These data show that there was improvement for most students. Those students with low planning scores improved from 44% to 205% over baseline, and those with high planning scores improved from 6% to 159% over baseline. These students do appear to have differentially benefited from the intervention, a finding that becomes more apparent when the aggregated data are examined.

The mean numbers correct during baseline and intervention are presented for the low and high contrast groups by seven session segments in Table 2. These scores suggest that although the two groups were similar during baseline (differing by only 1.4 points), the mean scores during each segment of the intervention differed considerably more (by about 6 points). The amount of change for the contrast groups during the intervention segments was more apparent when examined in relation to the baseline values.

The amount of change over baseline for the low and high groups based on planning scores is presented in Figure 1. These results show that the students who were low in planning improved considerably and consistently across the three intervention segments. They improved 49% over baseline during Sessions 1 through 7, 85% during Sessions 8 through 14, and 113% during Sessions 15 through 21 (80% overall). In comparison, the students with high planning scores improved 25% over baseline during Sessions 1 through 7, 29% during Sessions 8 through 14, and 72% during Sessions 15 through 21 (42% overall). These data show that the maximal effect for the students with low planning scores (113%) was achieved as the result of very consistent improvement across the three segments. The students with high planning scores improved somewhat (about half as much as the contrast group) during the first two intervention segments, but their greatest growth occurred during the last intervention segment. The rate of improvement for students with high planning scores, however, was still about 50% less than that seen for students with low planning scores.

A second set of analyses was conducted to further examine the extent to which groups defined by PASS scores showed differential improvement. The sample was re-sorted according to their simultaneous scores, and the low and high groups were contrasted. This comparison was especially important because, of the four PASS processes, simultaneous scores relate most highly to traditional IQ scores, especially the Performance Scale of the Wechsler IQ test (Das et. al., 1994). The results showed that the contrast groups based on simultaneous processing scores differed minimally—by only 4%—over the 21 intervention sessions. The low simultaneous group improved 50% over baseline during Sessions 1 through 7, 81% during Sessions 8 through 14, and 120% during

TABLE 1
Mean Number of Mathematics Problems Correct and Percentage Change Over Baseline for Each Student During Baseline and Intervention Segments

	Baseline (Sessions 1–7)	Intervention					
		Sessions 1–7		Sessions 8–14		Sessions 15–21	
	*M*Corr	*M*Corr	%Ch	*M*Corr	%Ch	*M*Corr	%Ch
Students low in planning							
LP1	7.8	14.8	89	19.8	153	24.0	205
LP2	7.3	5.1	–30	9.6	31	14.0	91
LP3	111.0	23.7	116	24.0	118	23.2	112
LP4	31.0	38.7	22	44.2	40	45.5	44
Students high in planning							
HP1	20.2	21.8	8	23.5	16	24.0	18
HP2	9.1	11.2	23	13.7	48	23.7	159
HP3	12.8	15.6	22	14.8	16	13.5	6
HP4	10.1	15.0	48	13.8	37	20.8	106

*Note. M*Corr = mean correct for seven session segments; %Ch = percentage of change over baseline using the number correct during intervention minus the number correct during baseline divided by the number correct during baseline, using seven session segments.

TABLE 2
Mean Number of Math Problems Correct During Baseline and Intervention Sessions for Students with Low and High Planning Scores

Session	Low planning	High planning
Baseline 1–7	14.5	13.1
Intervention 1–7	20.6	16.0
Intervention 8–14	24.4	16.5
Intervention 15–21	26.7	20.5
Intervention 1–21	23.7	17.6

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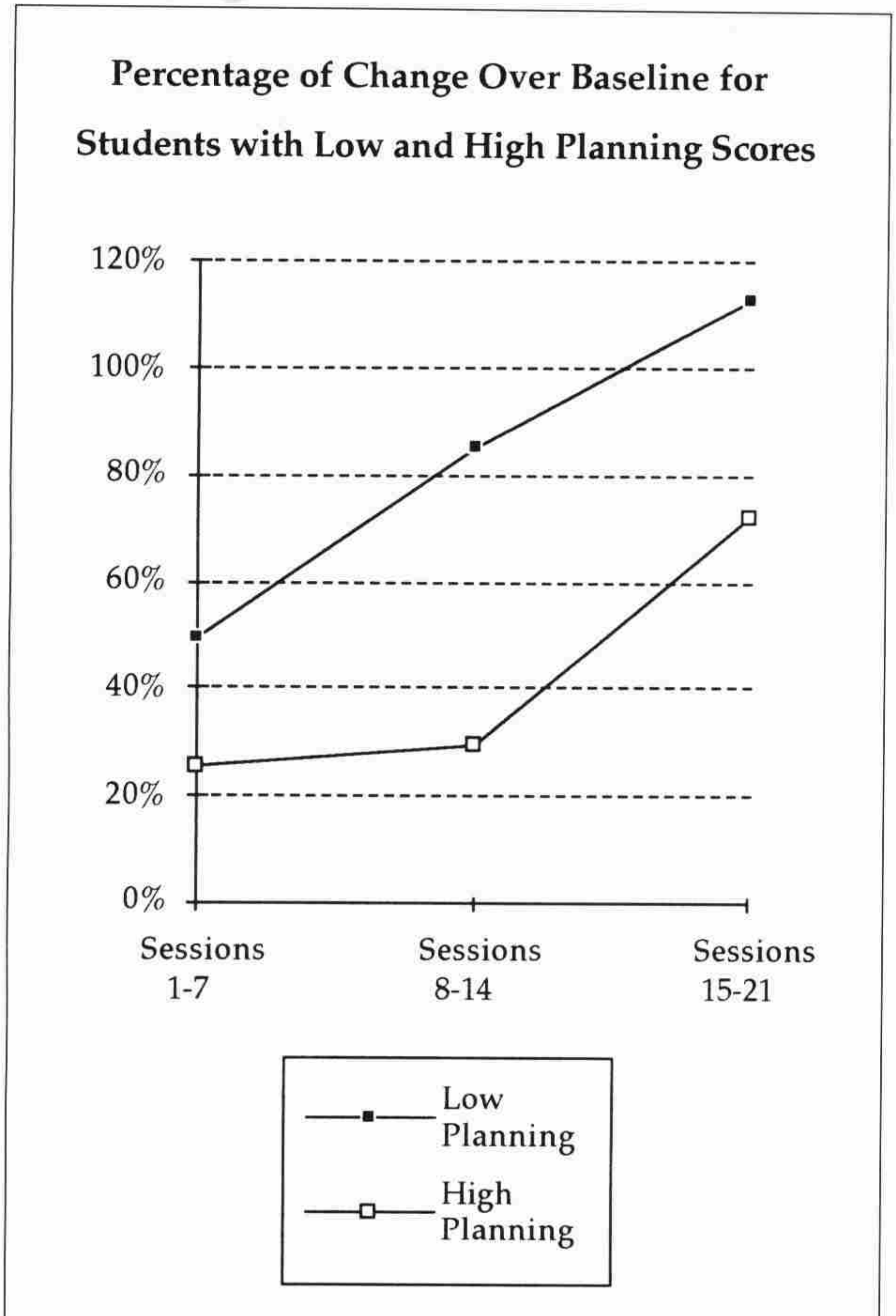

FIGURE 1. Percentage of change over baseline for students with low and high planning scores.

Sessions 15 through 21 (80% overall). Similarly, the students with high simultaneous scores improved 35% over baseline during Sessions 1 through 7, 54% during Sessions 8 through 14, and 137% during Sessions 15 through 21 (76% overall).

The differences between contrast groups defined according to successive and attention scores followed a different pattern. When ranked according to successive scores, the overall differences between baseline and intervention Sessions 1 through 21 were found to be 55% (22%, Sessions 1 through 7; 60%, Sessions 8 through 14; 90%, Sessions 15 through 21) for the low groups and 78% (55%, Sessions 1 through 7; 64%, Sessions 8 through 14; 115%, Sessions 15 through 21) for the high groups. This indicated that those with low scores on successive processing showed about 40% less gain over baseline than those with high scores. Similarly, when the contrast groups were defined by attention scores, the overall differences between baseline and intervention segments were 57% (39%, Sessions 1 through 7; 50%, Sessions 8 through 14; 90%, Sessions 15 through 21) for the low group and 76% (38%, Sessions 1 through 7; 54%, Sessions 8 through 14; 134%, Sessions 15 through 21) for the high group. The results, based on defining the samples on successive and attention scores, are the opposite of those obtained when planning scores defined the groups.

Discussion

The intent of this study was to determine if an instruction designed to facilitate planfulness given by teachers to their class as a group would have differential effects depending on the cognitive characteristics of the individual students, as was found in previous research (Cormier et al., 1990; Kar et al., 1992; Naglieri & Gottling, 1995). The results presented here suggest that the students with low planning scores improved more than those with high scores in planning because this instruction met their need to be more planful and because planning has been shown to be important for mathematics computation (Garofalo, 1986). These results, anticipated in light of previous research, indicate that teaching control and regulation of cognitive activity has beneficial effects for many students but is especially helpful for those who are poor in planning, as defined by the PASS theory. Because these results suggest that students will differentially benefit from this intervention, matching instruction to the specific cognitive weakness of the child is important, especially considering that this is the fourth time this result has been achieved.

When combined with the Cormier et al. (1990), Kar et al. (1992), and Naglieri and Gottling (1995) studies, the present results support the view that the PASS theory can provide useful information for instructional design, as suggested by Das et al. (1994), and thereby also support the applied utility and validity of the theory (Messick, 1995). Furthermore, this aspect of the PASS theory seems to address the calls for a theoretical model of cognitive processes that influence learning and learning failures (Geary, 1989; Kirby & Williams, 1991). Moreover, the accumulated research findings further suggest that PASS may meet the "need [for] a theory of the initial properties of the learner which interact with learning . . . [and] accounts for an individual's end state after a particular educational treatment" (Snow, 1989, p. 51). Thus, there is an increased probability that successful aptitude-by-treatment interactions (ATIs) may emerge if a specific and relevant aptitude is identified and a particular treatment tied to that specific aptitude is applied.

The ATI concept assumes that students low on one aptitude may do well given instructional approach A, whereas those high on the aptitude may do well given instructional approach B (Peterson, 1988). The data based on planning scores found in this study are consistent with the ATI concept; however, they are in contrast to past ATI research, which typically has found that students with low general ability improve little, whereas those with high general ability do well. The present data, especially when the results based on all four of the PASS processing scores are considered, suggest that ATI was not uniformly found. That is, the data for successive and attentional processes showed a pattern similar to past ATI research, whereby the lower the cognitive processing score, the less improvement, and the higher the cognitive processing scores, the greater the improvement. However, the opposite was found for planning. Interestingly, and importantly, the results for planning and attention were opposite, suggesting that these processes have different implications for instructional design. Clearly, they were related to academic performance in math computation in opposite directions.

Conclusions

The findings of this study support the idea that cognitive instruction may improve the mathematics performance of students who are poor in planning when they are given instruction that meets their cognitive needs. It is therefore suggested that poor planning processes should be considered as another important influence on mathematical performance, along with other variables, such as slow rates of execution (Kirby & Becker, 1988), deficient reading skills, and working memory limitations (Kirby & Williams, 1991). Because the intervention used in this study (a) required no special materials or extensive training to conduct, (b) was managed through collaborative consultation between the teachers and school psychologists in a relatively short period of time, and (c) seems to have been effective, it holds promise. The technique could be integrated into regular classroom activities and used at home by informed parents. Combining the technique with math instruction would likely provide maximum benefit. Future research should now be conducted to further replicate these findings for other groups of children, including those with and without learning problems, and to examine the differential benefits of facilitating planning along with, rather than separate from, math instruction.

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AUTHORS' NOTE

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