Fomenting Metacognitive Skills through Cooperative Learning in a Scientific Concept-Learning Task using Hypermedia

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Running head: Metacognition

Abstract

This study investigated the effects of peer modeling during learner-controlled computer based instruction, on performance and cognitive monitoring skills among high and low achievers. It was hypothesized that exemplary verbal modeling (articulation) of metacognitive skills by high-achieving students while learning in heterogeneous ability pairs (cooperative learning groups) will enhance the development of such skills among both high and low achievers. One hundred and eighty seven sixth-graders were divided into four treatment groups, based on prior knowledge grouping (heterogeneous pairs vs. homogeneous pairs) and modeling interaction (articulation vs. no articulation). The articulation version of the tutorial, using general scientific content, was embedded with prompts requiring students to articulate their metacognitive processes at decision-making points in the lesson. The results showed a significant Prior Knowledge X Grouping X Articulation interaction. The low prior knowledge students performed better when articulation was required, regardless of group composition, although this effect was not significant. Among the high prior knowledge students, there was a significant Grouping X Articulation interaction, such that subjects in homogeneous groups outperformed those in heterogeneous groups when not required to articulate; when required to articulate, subjects in heterogeneous groups outperformed those in homogeneous groups. These results indicate that peer modeling did not significantly improve the scores of low-achieving students, and that high-achieving students did worse in homogeneous groups when required to articulate, than in any other condition. These results suggest that requiring articulation may be an effective strategy in for learning in heterogeneous groups, but may hinder the performance of high-achieving students working together in homogeneous groups.

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This study investigated the effects of peer modeling during learner-controlled, computer based instruction, on performance and cognitive monitoring skills among high and low achievers. It was hypothesized that exemplary verbal modeling of metacognitive skills by high-achieving students while learning in heterogeneous pairs will improving learning among both high and low achievers.

Although permitting learners to participate in their own instructional decision-making is intuitively appealing, empirical evidence to support the notion has been contentious (Snow, 1980; Steinberg, 1977). Some researchers postulate that, among young students, poor cognitive monitoring results in ineffective use of provided options. Extensive research in the area of metacognition suggests that effective use of cognitive monitoring skills is also determined by level of prior knowledge and aptitude.

There has been a sporadic interest in improving awareness and application of learning strategies through cooperative learning. Temiyakarn & Hooper (1993) contend that cooperative learning is effective for improvement of higher levels of cognitive processing, because in cooperative learning groups students will observe, imitate and build upon each other's strategies. This in turn increases their mastery of higher-level reasoning skills (Johnson & Johnson, 1985). Furthermore, Spurlin, Dansereau, Larson, and Brooks (1984) found that individuals in cooperative-learning groups used metacognitive strategies more frequently than did individuals working alone, indicating a higher level of cognitive processing. They used the frequency of appropriate elaboration as an indication of subjects' use of metacognitive processing. Johnson, and Johnson (1981) examined the reasoning strategies involved in several areas across cooperative, individualistic, and competitive structures. Their results indicate that cooperative interaction promoted higher achievement and the discovery of superior cognitive reasoning strategies. The positive effects of cooperative learning have also been found in higher-level concept learning (Sharan 1980; Hooper, Temiyakarn, & Williams, 1993).

Review of literature

Researchers of learner control have been perplexed by its inadequacy as an effective strategy within individualized instruction. Transferring responsibility of instructional decision-making to learners in most instances has failed to improve performance and choice behavior (Carrier & Williams, 1988; Casey & Hannafin, 1986; Clark 1982; Steinberg, 1977). For example, it is not sufficient to merely provide options to learners in a lesson, without guidance on how to use them wisely (Boyd, Douglas & Lebel, 1984; Tobias, 1987). Learner control can be considered a meta-strategy, in which learners must exercise a high level of self-monitoring and an efficient use of embedded options (e.g., access to review, paraphrased material, elaborations, examples, sequencing etc.). However, younger or less-skilled learners are often lacking in knowledge of the use of strategies, as well as how to monitor strategy use when given the opportunity to do so. High achievers appear to exercise effective learner control, but low achievers perform particularly poorly under such conditions. Low achievers often lack sufficient self-regulatory strategies to make effective learner-control decisions (Ross & Rakow, 1981). One assumption is that learner control appears most effective when students use well-developed metacognitive abilities (Garhart & Hannafin, 1986).

Learning strategy research and the current study:

Considerable evidence suggests that students expend effort on strategies that do not work (Pressley, Borkowski, & O'Sullivan, 1984; Pressley, Ross, Levin, & Ghatala, 1984; Pressley, Levin, & Ghatala, 1984). Several studies have shown that students' on-task monitoring of performance is inefficient (Glenberg & Epstein, 1985; Palmer, Stowe, & Kueker, 1986). According to Ghatala, Levin, Pressley and Goodwin (1986), elementary school children often fail to monitor the effectiveness of strategies as they use them. One study (Casey & Hannafin, 1986) specifically explored the relationship between performance and comprehension monitoring during a computer-based task. Students' understanding of their own comprehension was periodically assessed as they progressed through the lesson. Findings from the study revealed that learners were unable to make accurate assessments of their own comprehension and hence, instructional needs. The authors considered poor monitoring a possible cause of the lack of persistence among learners when given control of their own learning. Carrier and Williams (1988) proposed that failure of sustained effort during learner-controlled instruction might stem from cognitive sources such as lack of accurate metacognitive knowledge.

In light of the detrimental effects observed when students are given complete control over their learning, a number of researchers have recommended interventions designed to compensate for these effects. The most often-cited suggestion is provision of some form of learner support, which operates in conjunction with the learner control strategy. Merrill (1987) favors learner control in all forms of computer-based instruction, but recommends that if students are not exercising decisions under their control wisely, the built-in "Monitor" should intervene and lead the student through instruction. Reigeluth (1979) suggests that a CAI system should provide a large degree of control over macro and micro instructional components, but it should also provide learners with the knowledge and information necessary for them to make good learner-control decisions. This study attempts to look at a learner control support system, stemming from the theory of cognitive monitoring.

Learning Strategies, Metacognition, and Cognitive Monitoring

Research on training skills interventions has been viewed from two different but related perspectives—learning strategy interventions and metacognition. Whereas learning strategies look at specific processes or strategies used during learning, metacognition examines higher-order self-regulatory processes.

Metacognitive strategies (Brown & Smiley, 1978) pertain to the student's ability to set goals for learning, estimate the success with which the goals are being met, and select alternative strategies to meet the goals. The design of learner-controlled, computer-based programs has been viewed from a metacognitive perspective, an idea that is extensively used in the acquisition of reading skills (Baker & Brown, 1983; Jacobs & Paris, 1987).

Cognitive monitoring refers to the learner's efforts to monitor their own performance in a learning task (Flavell, 1979). Recent investigations have revealed a close association between performance and cognitive monitoring. Owings and Peterson (1980) found that successful fifth-graders spontaneously monitored while reading, whereas less-successful students did not. They concluded that less-successful students might not perform well due to inadequate planning and regulating. Similar findings are reported by Palmer et al. (1986), who examined the use of look back strategy. They found that good readers used look backs more strategically and more often than poor readers and identified more consistencies in passages. According to these researchers, strategic use of look backs is a more sensitive indicator of identification of inconsistencies than reading time. Inadequacy of cognitive monitoring is also exemplified in other studies (e.g., Casey & Hannafin, 1986; Garner & Reis, 1981); Glenberg & Epstein, 1985; Tobias, 1987).

Vygotsky (1978) argues that all cognitive processes are *initially* social, shared between people, particularly between child and adult; and that the basic interpersonal nature of thought is transformed through experience to an intrapersonal process. Vygotsky also proposed that learning awakens a variety of developmental processes that are able to operate only when children are interacting with people in their environment and in cooperation with their peers. Once these processes are internalized, they become part of the child's independent developmental achievement repertoire.

In heterogeneous cooperative learning groups, when low ability students interact with high ability students in a problem-solving domain, a great deal of learning occurs. Indeed, some would argue that social processes shape the majority of learning. The development of cognitive control is very much a social process. Students first experience active problem solving activities in the presence of others, then gradually learn to perform these functions for themselves.

In the current study it was hypothesized that changing learners' patterns of decision-making through effective cognitive monitoring would lead to improved performance. The intervention consisted of peer modeling of metacognitive skills by higher-achieving students, through training of effective metacognitive behaviors and cooperative-learning skills. Students in this investigation were divided into four treatment groups: homogeneous with articulation, homogeneous without articulation, heterogeneous with articulation, and heterogeneous without articulation, and required to complete a hypermedia concept-learning tutorial. Prompts requiring students to articulate their metacognitive processes were embedded the "articulation" tutorials, especially at decision-making points in the lesson. Training was provided in cooperative learning processes as well as in computer skills. Verbal articulation of strategies by high-achieving students was predicted to lead to the transfer of such skills to their lower-achieving partners and improve their achievement.

Methods

Subjects

183 sixth-graders of middle-class background were used in the study. Students were stratified by prior knowledge and assigned to cooperative learning groups based on two factors (level of articulation and level of grouping), so that the study comprised four treatment groups: 1) a heterogeneous group with a lesson that required articulation; 2) a homogeneous group with a lesson that required articulation; 3) a heterogeneous group with a lesson that did not require articulation; and 4) a homogeneous group with a lesson that did not require articulation.

Materials

Training. There were two training sessions: cooperative training and computer training**.** Cooperative training was designed to enhance intra-group interaction and cooperation. Computer training was designed to provide familiarity with using the keyboard and mouse as input devices during the computer-based lesson.

Pretest. The pre-test included 25 items that required generation of basic science concepts in order to answer correctly. Pre-test scores were used for assigning students to level of prior knowledge (high or low). The K-R 20 reliability for the pre-test was 0.85

Computer-presented content. The computer-based tutorial used for the study was designed and developed by the experimenter using biological concepts that were used in another studies on learner control and cooperative learning (Relan, 1991; Temiyakarn & Hooper, 1993). The topic of Ecology was selected because it is one of the sixth-grade curricular units. A conceptual, learner-controlled lesson was programmed in a hypermedia format with two different versions: one with verbal articulation required and one with no verbal articulation required. The authoring environment Authorware (Macromedia Inc., San Francisco, CA) was used to develop the lesson.

Post-tests. A 25-item multiple choices test, consisting of 10 items on verbal information and 15 items on generalization, was used as a post-test. This test was used for both immediate and delayed post-tests. Students completed the post-test immediately after the experiment and again approximately one week following the experiment. Students completed both pre- and post-tests individually.

Design

A randomized block design was used with prior knowledge as a blocking factor (low and high) and two cross-experimental factors: grouping composition (heterogonous and homogeneous) and level of articulation (articulation and non-articulation). Because the effects of interest occurred within level of prior knowledge, analyses were conducted on experimental effects nested within each blocking level. For group-based measures within level of prior knowledge, a completely randomized design was employed with two cross-experimental factors: grouping (heterogonous and homogeneous) and the articulation strategy (articulation and non-articulation). Two dependent measures were analyzed: immediate and delayed post-tests. Achievement effects were analyzed using MANOVA for delayed and immediate post-tests individually.

Experimental procedures

Students completed each training session in approximately 50 minutes. The training was completed in intact classes. Both training sessions were repeated five times, once for each class, and each subject received two training sessions. The two training sessions were completed a week apart. Students were given a pretest pertaining to the lesson content the week before the start of the study.

Students were assigned to treatment groups using stratified random sampling. Initially, high- and low-prior knowledge students were randomly assigned to pair in heterogeneous groups and students with the same prior knowledge status were paired in homogeneous groups. They were thus divided into four groups/according to the treatment levels described above, while blocking for prior knowledge. All students completed the computer-based lesson in cooperative learning groups. Post-tests were administered immediately after lesson completion. The same test was administered 7 days later as the delayed post-test.

Results

<u>Immediate Post-test</u>

The homogeneous non-articulation group showed the highest scores (Mean = 18.07) at the high prior knowledge level. The homogeneous articulation group showed the highest mean score (Mean = 15.00) at the low prior knowledge level.

Insert Table 1 About Here

The results showed a significant Prior Knowledge X Group composition X Articulation interaction (MS = 99.72, F (1, 175) = 3.998, p = .047).

Insert Table 2 About Here

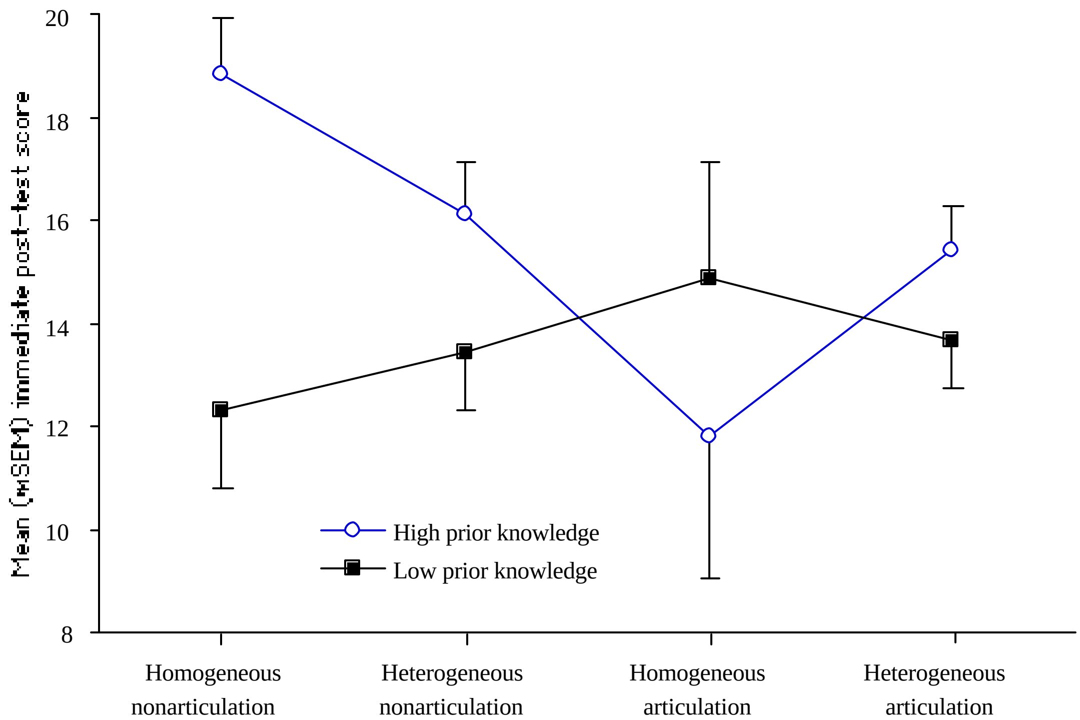

Figure 1. The interaction of Level of Articulation, Group Composition, and Prior Knowledge Level.

The comparison between high and low prior knowledge was not the priori interest of this study. This study analyzed data within high prior knowledge subjects separately from data within low prior knowledge subjects.

High Prior Knowledge group There was no significant difference between homogeneous and heterogeneous groups within the high prior knowledge level. There was a significant difference ($F(1, 87) = 4.79$, $p = .03$) between the two treatment groups (articulation and non-articulation) among high prior knowledge students. The non-articulation group outperformed the articulation group among the high prior knowledge students. There was also a significant interaction ($F(1,87) = 5.981$, $p = .01$) between the articulation and group composition treatment factors.

Insert Table 3 About Here

Follow up tests indicated that the homogeneous group not requiring articulation outperformed the Homogeneous group requiring articulation. There was no difference between non-articulation and articulation heterogeneous groups (Figure 2).

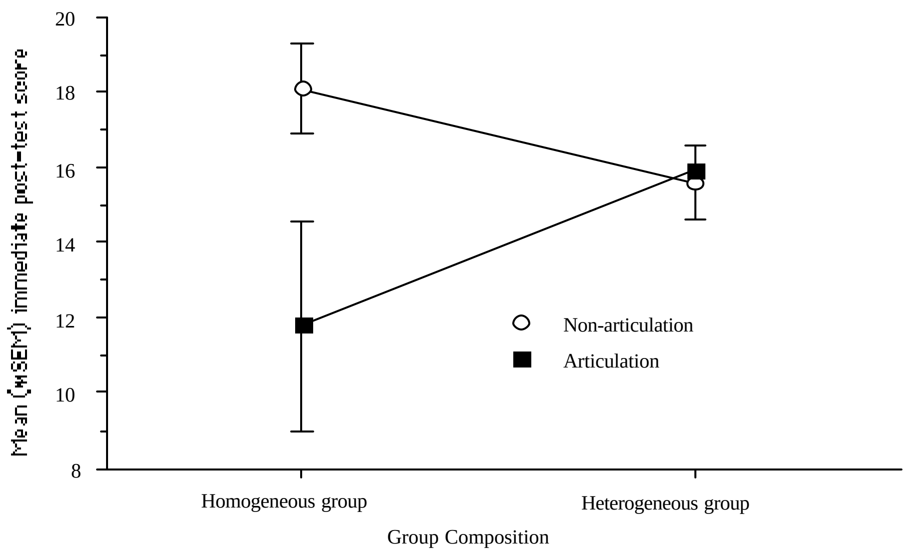

Figure 2. The interaction of articulation and group composition among high prior knowledge students.

<u>Low Prior Knowledge group</u> The low prior knowledge students performed better when articulation was required, regardless of group composition, although this effect was not significant.

Insert Table 4 About Here

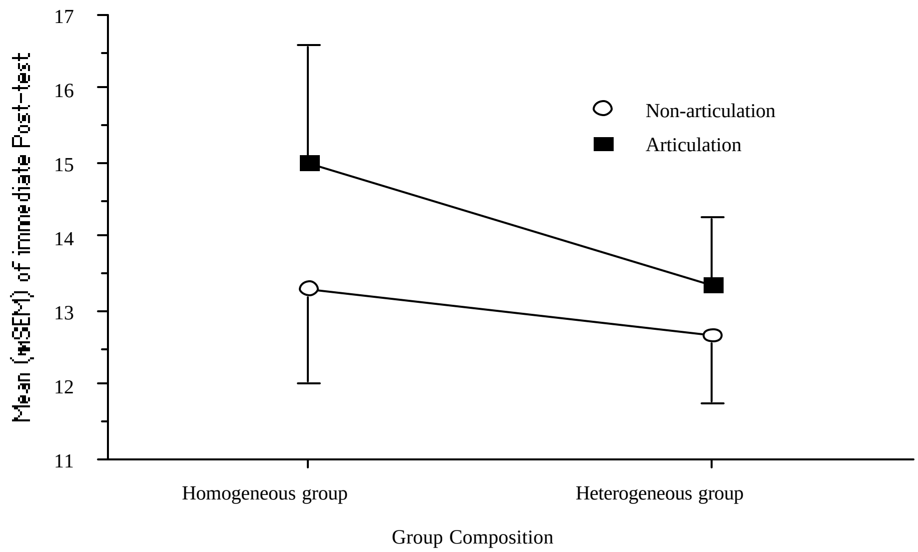

Figure 3. The interaction of articulation and group composition among low prior knowledge students.

Delayed Post-test

The high prior knowledge students in the non-articulation homogeneous groups showed the highest mean score of all treatment groups.

Insert Table 5 About Here

However, there were no significant differences among the treatment groups on delayed post-test. There were also no significant interactions among the three factors.

Insert Table 6 About Here

Discussion

The main purpose of this study was to examine the effect of using metacognitive strategies to enhance learning in cooperative learning groups pairing students with high and low prior knowledge. The study also examined the effects of pairing students in homogeneous and heterogeneous cooperative learning groups. The results suggested that among the high prior knowledge students, the homogeneous group outperformed the heterogeneous groups when not required to articulate. When they were required to articulate, subjects in the heterogeneous group outperformed those in the homogeneous group. In this respect, the high achieving students did worse in the homogeneous group when required to articulate than in any other condition. On the delayed post-test this difference was not significant, due primarily to a 2-point increase in performance of the high achieving students in the homogeneous articulation group. The scores of all other treatment groups changed only slightly (Table 6.). This phenomenon has been observed before. Temiyakarn and Hooper (1993) reported that students in cooperative-learning groups performed better on the delayed post-test than on the immediate post-test, presumably because they discussed the lesson content during the intervening week.

These findings may reflect the nature of intra-group interaction. High achievers may generate their own metacognitive strategies and may be confused with their partner's strategies when they have to generate verbal explanations during the articulation (Hooper et al., 1993). This may have impaired performance on the immediate post-test in homogeneous groups when required to articulate and enhanced performance in homogeneous groups when not required articulating. These results show that the notion that high achievers perform the same in homogeneous and heterogeneous groups may be too simple—performance may be mediated by higher-level factors such as the nature and degree of articulation.

Among low prior knowledge students, peer modeling slightly but not significantly improved scores when they were required to articulate. It is possible that the performance of low prior knowledge subjects would improve gradually if they continued using this matacognitive strategy. They may need more extensive training on metacognitive strategies to make the effect of using the strategies more apparent. Another factor mediating the scores of the low prior knowledge students is the group composition. Because students were assigned to groups using a median split, the lowest and highest prior knowledge students were paired with students toward the middle of the distribution. By alternatively pairing the highest and lowest prior knowledge students together in groups, the positive effects of modeling of metacognitive strategies may become more apparent.

These results suggest that requiring articulation may be an effective strategy for learning in heterogeneous groups, but may hinder the performance of high-achieving students working together in homogeneous groups. Forcing students to stop periodically during learning and verbalize their thinking processes leads to improved performance only when they work in cooperative heterogeneous groups. Grouping very high and very low prior knowledge students may increase the size of this effect. The intervening treatment designed in the current study was an adaptation of the successful aspects of cooperative learning, integrated with the assumption that metacognitive skills are a determinant of effective learning.

References

Baker, L., & Brown, A. L. (1984). Metacognitive skills and reading. In D. Pearson, R. Barr, M. Kamil & P. Mosenthal (Eds.), *Handbook of Reading Research* (pp. 353-394). New York: Longman.

Boyd, G. M., Douglas, L., & Lebel, C. (1984). Learner support options in computer-assisted learning. *Computer Education*, *4*, 349-354.

Brown, A. L., & Smiley, S. S. (1978). The development of strategies for studying texts. *Child Development, 49*, 1076-1088.

Carrier, C. A., & Williams, M. D. (1988). A test of one learner-control strategy with students of differing levels of task persistence. *American Educational Research Journal*, *25*, 285-306.

Casey, G., & Hannafin, M. (1986). The accuracy of cognitive monitoring during computer-based instruction. *ERIC Document System Proceedings*, ED 267 768.

Clark, R. E. (1982). Antagonism between achievement and enjoyment in ATI studies. *Educational Psychologist*, *17*, 92-101.

Flavell, J.H. (1979). Metacognition and cognitive monitoring *American Psychologist*, *34*, 906-11.

Garhart, C., & Hannafin, M. J. (1986). The accuracy of cognitive monitoring during computer-based instruction. *Journal of Computer-Based Instruction*, *13*, 88-93.

Garner, R., & Reis, P. (1981). Monitoring and resolving comprehension comprehension obstacles: An investigation of spontaneous text lookbacks among upper grade good and poor comprehenders. *Reading Research Quarterly*, *16*, 569-582.

Ghatala, E., Levin, J. L., Pressley, M. and Goodwin, D. (1986). A componential analysis of the effects of derived and supplied strategy-utility information on children's strategy selections. *Journal of Experimental Child Psychology*, *41*, 76-92.

Glenberg, A. M., & Epstein, W. (1985). Calibration of comprehension. *Journal of Experimental Psychology: Learning, Memory and Cognition,11*, 702-718.

Hooper, S., Temiyakarn, C., & Williams, M. D. (1993). The effects of cooperative learning and learner control on high- and average-ability students. *Educational Technology Research and Development*, *41(2)*, 5-18.

Jacobs, J. E. & Paris, S. G. (1987). Children's metacognition about reading: Issues in definition, measurement and instruction. *Educational Psychologist*, *22(3&4)*, 255-278.

Johnson, and Johnson (1981). Effect of cooperative and individualistic learning experiences on interethnic interaction. *Journal of Educational Psychology*, *73*, 244-249.

Johnson, D. W., & Johnson, R. T. (1985). Cooperative learning: One key to computer assisted learning. *The Computing Teacher*, *13(2)*, 11-15.

Merrill, M. D. (1987). The new component design theory: Instructional design for courseware authoring. *Instructional Science*, *16*, 19-34.

Owings, R.A., & Petersen, G.A. (1980). Spontaneous monitoring and regulation of learning: A comparison of successful and less successful fifth graders. *Journal of Educational Psychology, 72(2),* 252-256.

Palmer, D. J. , Stowe, M. L., & Kueker, J. (1986). A computer-assisted on-line investigation of comprehension monitoring. *ERIC Document System Proceedings,* ED 270 716.

Pressley, M., Borkowski, J. and O'Sullivan, J. T. (1984). Memory strategy instruction is made of this: Metamemory and durable strategy use. *Educational Psychologist, 19*(2), 94-107.

Pressley, M., Levin, J. L. & Ghatala, E. S. (1984). Memory strategy monitoring in adults and children. *Journal of verbal learning and Verbal Behavior*, *23*, 270-88.

Pressley, M., Ross, K. A., Levin, J. L. and Ghatala, E. S. (1984). The role of strategy utility knowledge in children's strategy decision making. *Journal of Experimental Child Psychology*, *38*, 491-504.

Reigeluth, C. M. (1979). TICCIT to the future: Advances in instructional theory for CAI, *Journal of Computer-based Instruction*, *6*(2), 40-46.

Relan, A. (1991). *Relationships among organisms*. Unpublished computer progam.

Ross, S. M., & Rakow, E. A. (1981). Learner control versus program control as adaptation strategies for selection of instructional support for math rules. *Journal of Educational Psychology*, *73*, 745-753.

Sharan, S.(1980). Cooperative learning in teams: Recent methods and effects on achievement, attitude, and ethic relations. *Review of Educational Research*, *50*, 241-272.

Snow, R. E. (1980). Aptitude, learner control, and adaptive instruction. *Educational Psychologist*, *15*, 151-58.

Spurlin, J. E., Dansereau, D. F., Larson, C. O., & Brooks, L. W. (1984). Cooperative learning strategies in progressing descriptive text: Effects of role and activity level of the learner. *Cognition and Instruction*, *1*, 451-463.

Steinberg, E. R. (1977). Review of student control in computer-assisted instruction. *Journal of Computer-based Instruction*, *3*, 84-90.

Temiyakarn, C., & Hooper, S. (1993). The effects of Cooperative learning and learner control on high and low achievers. *ERIC Document System Proceedings,* 1021-1038.

Tobias, S. (1987). Mandatory text review and interaction with student characteristics. *Journal of Educational Psychology*, *79*, 154-161.

Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes* (M. Cole, V. John-Steiner, S. Scibner & E. Souberman, Eds. & Trans.). Cambridge, MA: Harvard University Press.

Table 1. Descriptive statistics for the immediate post-test.

	Count	Mean	Std. Dev.	Std. Error
low, non-articulate, Homo gr.	10	13.300	4.057	1.283
low, non-articulate, Hetero gr.	35	12.657	5.401	.913
low, articulate, Homo gr.	10	15.000	4.967	1.571
low, articulate, Hetero gr.	37	13.351	5.417	.891
high, non-articulate, Homo gr.	14	18.071	4.480	1.197
high, non-articulate, Hetero gr.	33	15.576	5.286	.920
high, articulate, Homo gr.	5	11.800	6.221	2.782
high, articulate, Hetero gr.	39	15.923	4.094	.655

Table 2. Omnibus MANOVA table for the immediate post-test.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	21.374	21.374	.857	.3559
group composition	1	.757	.757	.030	.8619
prior	1	85.542	85.542	3.430	.0657
prior * treatment	1	118.693	118.693	4.759	.0305
prior * group composition	1	26.344	26.344	1.056	.3055
prior * treatment * group c…	1	99.720	99.720	3.998	.0471
treatment * group compositi…	1	54.043	54.043	2.167	.1428
Residual	175	4364.977	24.943		

Table3. ANOVA table for the immediate post-test for high prior knowledge students.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	107.202	107.202	4.791	.0313
Group Composition	1	8.090	8.090	.362	.5492
Treatment * Group Comp.	1	133.816	133.816	5.981	.0165
Residual	87	1946.558	22.374		

Table 4. ANOVA table for the immediate post-test for low prior knowledge students.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	22.427	22.427	.816	.3688
Group Composition	1	20.544	20.544	.748	.3896
Treatmentnt * Group Comp.	1	3.958	3.958	.144	.7052
Residual	88	2418.418	27.482		

Table 5. Descriptive statistics for the delayed post-test.

	Count	Mean	Std. Dev.	Std. Error
low, non-articulate, Homo gr.	10	14.000	3.972	1.256
low, non-articulate, Hetero gr.	34	12.412	5.614	.963
low, articulate, Homo gr.	9	13.667	5.268	1.756
low, articulate, Hetero gr.	37	13.189	5.436	.894
high, non-articulate, Homo gr.	14	18.214	4.441	1.187
high, non-articulate, Hetero gr.	33	15.091	4.901	.853
high, articulate, Homo gr.	5	13.800	4.438	1.985
high, articulate, Hetero gr.	38	15.105	4.305	.698

Table 6. Omnibus MANOVA table for the delayed post-test.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
prior	1	134.276	134.276	5.425	.0210
treatment	1	26.274	26.274	1.061	.3043
group composition	1	25.326	25.326	1.023	.3132
prior * treatment	1	39.397	39.397	1.592	.2088
prior * group composition	1	.103	.103	.004	.9487
treatment * group composition	1	51.520	51.520	2.081	.1509
prior * treatment * group composition	1	18.483	18.483	.747	.3887
Residual	172	4257.374	24.752		