The Effects of Computer-Generated Visuals on Word-Problem Solving*

by

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Paper presented at the Hong Kong ERA Fifth Annual Conference

from 26 & 27 Nov. 1988

* Based on Ph.d. Dissertation at the University of Minnesota, U.S.A.

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### Introduction

The ability to solve word problems is one of the most important objectives in the study of mathematics. Yet teaching word problem solving is recognized to be difficult. One of the reasons for this difficulty is that finding appropriate solutions to word problems is a complex task and indications of this complexity can be gleaned by reviewing studies which report that students score lower on word-problem solving than on computation (NAEP, 1979). To counteract the difficulty of solving word problems, many mathematicians and teachers have proposed untested methods to help students. Of the many hints, strategies and methods, the use of visuals is one that is widely endorsed (e.g., Davis & McKillip, 1980). However, very few empirical studies have shown positive results on the effectiveness of self generating visuals for solving word problems in elementary schools.

With the availability of microcomputers in schools and in classrooms, the emphasis on the use of computers for word-problem solving has shifted from process research to classroom application (e.g., Anand & Ross, 1987). One distinct advantage of computers over other traditional instructional modes is their ability to offer individualized instruction by adapting instructional materials to suit individual needs. For example, in computer-based instruction (CBI), some levels of control can be given to students to allow them to make choices in the selection of additional instruction. There is evidence that increased control promotes feelings of self-efficacy and self-determination and assists students to become independent and responsible learners (Gay, 1986). Many learner-control studies have investigated the influence of one or more individual characteristics such as cognitive styles, learning styles and ability levels on learner-control strategies in CBI. But other factors outside the individual, such as social and cultural climate, may also determine how well these strategies work. No studies, however, have looked into other characteristics not under the control of the individual that could influence learner-control strategies.

**Visual representation in word problems**

Understanding and creating internal representation of a problem situation forms an important initial step toward successfully solving word problems (Greeno, 1978; Hayes & Simon, 1977). Many have suggested that building students' competence in this initial step can help them be better problem solvers (e.g., Lester, 1985). Courses in problem-solving have emphasized this aspect and have taught various techniques of representing problem situations (e.g., Cyert, 1980). Similarly, Mayer (1985) proposes that training students to represent problem situations can improve their word-problem solving skills. Training activities like rephrasing problem situations, rewording the problem situation into another context, deriving equations, and drawing visuals (pictures and diagrams) have been suggested.

A number of theoretical propositions have been proposed to account for the importance of drawing visuals during solving word problems. Lesh and Akerstrom (1982) believe that forming an external representation by drawing visuals helps young problem solvers refine their mental representations. The iteration process of forming internal (mental) and external representations may lead to the generation and selection of more refined representations and thus, to the solution. Kaufmann (1985) cites research studies to support his theory that problem solvers process a problem visually when the problem task is new and novel, but if they are familiar with the task, will switch to verbal processing.

Although theoretical propositions indicate that drawing visuals is helpful, this procedure is not frequently practiced by many people. However, there is evidence to show that expert problem solvers draw visuals to represent problem situations more often than novices do. Heller and Greeno (1979), after reviewing a number of studies that investigated word-problem solving in arithmetic, physics, and thermodynamics, note that experts construct diagrams whenever they are useful while novices rely mainly on verbal statements. On the other hand, children do not draw visuals or diagrams to help them solve word problems. Ekenstam and Greger (1983) conducted a large scale survey of sixth-grade children's strategy in solving word problems. In one of the subtasks, students were asked to assess the correctness of a worked answer to a word problem. Most students concentrated on determining the accuracy of the calculation and very few bothered to check on the set-up of the problem. Hardly any students drew visuals to help in the solution.

**Effects of visuals on word-problem solving**

It is well known that visuals lend to better performance than words in paired-associate learning because of the dual channels for encoding information (Paivio, 1971). Visuals have also been incorporated in textual materials to help in comprehension and to aid in recall. However, in word-problem solving, the functions of supplied visuals are not clear. It has been hypothesized that visuals help students (a) to conceptualize the problem, (b) symbolize the problem situation through familiar images, and (c) to understand the problem better (Campbell, 1984).

The literature on the effectiveness of visuals in solving word problems has produced contradictory results. Threadgill-Sowder and Sowder (1982) in their review of literature reported several studies which showed that young students performed better when word problems were accompanied by visuals. Most of the studies reviewed involved subjects solving word problems in a testing situation without any extra instruction or practice in using the visuals to solve the problems. While visuals are effective in group testing situation, they are not when students are tested individually or when time constraint is imposed. Further studies by Sowder and associates (Moyer, Sowder, Threadgill-Sowder and Moyer, 1984; Threadgill-Sowder & Sowder,1982; Threadgill-Sowder, Sowder, Moyer, & Moyer, 1985) have consistently shown that students obtain higher scores when word problems are presented in a visual format than in the verbal format. Moyer et al. (1984) suggested that word problems presented visually help to reduce reading-related working memory overload, recall similar past experience and link visuals to appropriate schema, provide another channel to enable students to understand the problem situation, and organize the problem information to facilitate the selection of appropriate schema and the recall of data for computation.

While word problems accompanied with visuals help to enhance word-problem solving performance, the effects of pupils self-generating visuals are not so clear. Three studies showed that some form of training in the use of visuals in word-problem solving heightens performance (Canner, 1979; Nelson, 1974; Yancey, 1981) . One study showed no difference in performance when visuals were generated by students (Wersen, 1981), and another showed that it was difficult for students to generate pictorial representations of the problem statement without training (Walter, 1984).

These contradictory results from different studies can perhaps be explained by the variability of the design. Length of treatment, age of subjects, type of problems, and the type of covariates, are some factors that will affect the results of the studies. The ability to generate visuals and to use them depends not only on the age and ability of students, but also on the type of word problems and the type of visual tasks involved. Word problems involving complex concepts (e.g., proportion and commutativity) as used in Wersen's and Walter's studies, can influence the effectiveness of the method of self-generation of visuals.

## Learner Control

One exciting feature of computer-based instruction is its ability to offer various types of options for learners. Options such as selecting the amount and type of materials, specifying the type of instructional strategies, and choosing the amount of instructional support are commonly incorporated into CBI materials.

It is generally believed that it is advantageous to allow students to exercise control in the learning process. It has been postulated that allowing students to make decisions during the learning process will improve achievement by increasing motivation, reducing anxiety, and improving attitude toward learning (Steinberg, 1984). Most research studies in CBI have not provided support for this notion and have in fact found negative correlations between control and achievement (Carrier, 1984; Hannafin, 1984; Steinberg, 1977). However, students are able to judge their own learning ability provided they are given advice about their progress ( e.g., Johansen & Tennyson, 1983). Snow (1980) states that it is not a question of whether students should or should not be given control, but of how the control of instruction should be granted, to whom and under what conditions. If students are given these options, do they exercise them wisely and effectively?

Students can be given the choice of selecting the types or amount of materials they deem most suitable for their needs. But most students are not good judges; this is especially true for young students. While it is important for less able students to obtain more instructional support (Clark, 1982), they did not seek it when allowed to control lessons (e.g., Carrier, Davidson, & Williams, 1985; Hannafin, 1984). Fisher, Blackwell, Garcia & Greene (1975 ), investigated the effects and the pattern of selection of problems by fourth and fifth graders during an arithmetic CBI lesson. Some students consistently chose the easiest problems; others chose the more difficult problems. Tennyson & Buttery (1980) found that twelve graders, when given complete control of lessons, tended to choose an amount of material insufficient to master concepts and to terminate lessons too early. This resulted in poor achievement scores. On the other hand, students who received advisement about their progress toward the mastery of concepts, stayed on-task long enough to master the concepts. College students are better judges of the amount of practice and were able to judge and select an appropriate quantity of practice items required to master mathematical concepts (Judd, Bunderson & Bessent,1970). But they over-practiced and, consequently, took more time to complete a module (Lahey & Crawford,1976). The ability to be good judges, thus, will depend on the age and ability level of the students. Hannafin (1984) suggests that older and more academically capable students may have more refined cognitive strategies and are able to apply them to instruction. But younger children and less able students may not have neither the refined cognitive strategies nor the self-evaluation skills needed to monitor their own progress during instruction.

Besides age, ability, and personal characteristics (e.g., level of motivation), factors such as the cultural, social, and educational environment can influence students opting for additional instructions during the lesson. Numerous cross-cultural studies have indicated that Asian students (e.g., Japanese and Taiwanese) are more positive toward school learning (Walberg, Harnisch, & Tsai, 1986) and spend more hours on homework and on after-school instruction (White, 1985; Walberg et al., 1986; Harnisch, Walberg, Tsai, Sato, & Fyans, 1985). Social factors such as parental support and cultural emphasis on education have been cited as the main contributors to the higher mathematics achievement of Asians (Miura, 1987). Perhaps, these factors and the extra instruction students receive can influence students' task persistence and on their selection of the amount of instruction.

**The Current Study**

One purpose of the current study was to investigate the effectiveness of the strategy of using visuals to represent problem situation for solving word problems. It compares two different methods of using visuals: supplied visuals versus self-generated visuals. Reading ability, computation ability and spatial visualization are some individual difference factors that have been found to be correlated with students' word-problem solving performance ( Landau ,1984; Muth, 1984). These factors will be used as covariates.

Another purpose was to extend the range of variables of how learners operate when given options to select additional instruction. Social factors, such as parental support for learning and heavy cultural emphasis on education as a means of financial success, have been cited as reasons for the Asian emphasis on the importance of learning in schools (Miura, 1987). This attitude may influence students to select additional instruction when given the choice, a speculation that was explored in the current study. The following questions are addressed in the current study:

1. Can the use of visuals to represent problem situations be an effective strategy for solving word problems?

2. Will students select additional word problems when given the opportunity? And, when students are provided with visuals, will they select more word problems than when they must generate their own visuals?

## Methods

### Subjects

Participants (n=138) were 4th grade students from two primary schools in Singapore. These students follow a six-year primary curriculum consisting of studies in the first language (English), a second language (Chinese, Tamil or Malay), science, mathematics, social studies, and esthetics. At the end of their sixth year, students sit for a national examination, Primary School Leaving Examination, and if successful, proceed to secondary education. Few students have had any regular exposure to computer work.

Using a random set of numbers, students names were drawn from the school register and were assigned to six cells of a 3 x 2 design (three levels of visuals by two levels of learner-control). Due to various reasons, 12 subjects were eliminated leaving 21 subjects per cell.

### Instrumentation

The Comprehensive Tests for Basic Skills, Form U, Level F (CTB/McGraw-Hill, 1981) was used for testing students' reading comprehension skills and the Form U, Level G for the computation skills. The Punched Holes Test ( Wilson, Cahen, & Begle, 1968) for elementary school students was used for assessing students' spatial visualization ability. This test, an adaptation from the adult ETS Paper Folding Test (French, Ekstrom & Price, 1963 ), was modified for children by the National Longitudinal Studies of Mathematical Abilities (NLSMA) Group in 1967. The word problems were drawn from previous research projects (Sowder, Threadgill-Sowder, Moyer & Moyer, 1984; Yancey, 1981). These word problems were similar to those found in school textbooks. Basically, each problem consisted of two parts. In the first part, information with numerical values describing the problem situation was presented and in the second part, a question was posed. Two criteria were used for the selection of word problems: (a) the problems must be appropriate for third to fifth graders and (b) the problems must involve double-step arithmetic operations (e.g. multiplication and then addition). The reliability coefficient (KR 20) of word problems used during lessons was .79, and for the fifteen word-problem posttest was .78.

**Treatment**

There were three visual treatments, visual-supplied, self-generated, and no-visual; and two option-control treatments, learner-control and program-control.

Visual-supplied treatment. The visuals appeared for all the problems and examples in the three lessons. Simple iconic visuals with labels representing each problem were drawn. For example, to show five thousand three hundred trees, a group of trees were drawn with the label "5300 Trees." There were no attempts to represent the actual number of items in the visuals. Some problems required only two visuals to represent the problem while some required three. Figure 1 illustrates a sample visual screen for the word problem.

Self-generated treatment. For this treatment, subjects had to draw their own visuals on papers provided. To help subjects in drawing visuals, examples in the lessons were accompanied with visuals (same visuals as those in the supplied-visual treatment).

Specific instructions on how to draw visuals were provided. Subjects were told to draw a group of articles and attached a label to them. Instead of visuals appearing, a prompt "Draw pictures to help you" was presented. Also to encourage them to draw visuals, subjects were told that they would be awarded an extra point for visuals drawn in each problem.

No-visual treatment. This was the control treatment. The treatment procedure was the same as the visual-supplied group except that visuals were not presented. To maintain consistency, the keyboard was locked for fifteen seconds before subjects were allowed to key-in their answers to the word problem.

Learner-control treatment. For Lessons 2 and 3, subjects were allowed to choose the number of problems they would see. In order to prevent students from not solving any problems, they had to work out three word problems before being given the option to select more problems. On completion of the three problems, subjects were asked whether they would like to try another problem. If positive, another problem was presented. If negative, the lesson terminated and the total scores were shown. This choice was presented until the total number of problems reached eight. At that point, the lessons terminated and subjects were informed of their scores. The maximum number of problems chosen for Lessons 2 and 3 was eight (3 mandatory and 5 optional) and the minimum number was three ( 3 mandatory and no optional problems).

Program-control treatment. Under this mode, subjects did not have a choice in selecting the number of problems to solve. Instead , each subject would have to solve four problems in Lesson 1 and five problems each in Lessons 2 and 3.

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Insert Figures 1 and 2 about here

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**Procedures**

Before the collection of data, subjects were given the reading, computation, and spatial visualization tests. Subjects attended three CBI lessons, each lasting from thirty to forty-five minutes. The first lesson was an orientation one and scores were not collected. The lessons were delivered on Apple IIe computers in the schools' computer laboratories. Each computer station was then numbered so that subjects could be randomly assigned to the stations and thus, to different treatments. Within each session, all of the six treatments were present.

A typical task during the lesson consisted of the following sequence. A word-problem situation was presented at the top of the screen for students to read. They were advised to read the problem carefully. After a lapse of five seconds, instructions were provided for subjects to press the return key for the presentation of visuals. The visuals appeared followed by a time delay of ten seconds during which the keyboard was locked. After the pause, the problem question appeared. This procedure was adopted to prevent impulsive actions and also to encourage subjects view the visuals. Subjects then typed in their answers which were judged and if wrong, were shown the correct answer. On pressing the return key, five options for the selection of process operations were presented (Figure 2). Subjects selected one process operation that was perceived would yield the correct numerical answer. If successful, they would proceed to the next problem. If unsuccessful, the prototype solution , which explained how the answer was obtained, was presented. They would then proceed to the next problem. The first lesson lasted for approximately thirty to forty-five minutes. For Lessons 2 and 3, subjects were required to sit at their assigned microcomputer stations which were loaded with the programs they were working on previously. Subjects who completed their lessons ahead of others were sent back to their class.

**Results**

Table 1 shows the correlations between individual-difference variable scores and both on-task and posttest scores. Using multiple regression techniques, computation and spatial visualization scores accounted for 13 to 15% of the variance in the on-task scores; and 35% in posttest.

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Insert Table 1 about here

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Tables 2 & 3 show the means and standard deviations of scores for correct answers and process during the on-task lessons and the posttest , respectively.

Multivariate analysis of covariance (MANCOVA) was used to analyze the data with On-Task Answer and On-Task Process as combined dependent variables. Computation was used as a covariate variable. The main effect for visual treatment was found to be not significant.

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Insert Tables 2 & 3 about here

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In posttest scores, computation and spatial visualization scores were used as covariates with the Posttest Answer and Posttest Process as combined dependent variables. The main effect for visual treatments was significant $F$ (4, 236) = 4.26, $p$ < .01. Both Posttest Answer and Postttest Process scores showed highly significant visual treatment effects with $F$ (2,118) = 7.76, $p$ <.001 and $F$ (2,118) = 8.45, $p$ < .001, respectively. Simple contrast showed that the means of the self-generated group were significantly higher than both the visual-supplied and no-visual groups but not between the supplied-visual group and the no-visual group.

Subjects in the learner-control group attempted an average of five more problems than subjects in the program-control group (Table 4) but the On-Task performance for the two groups was not significant. Univariate analysis of the Posttest Answer and Posttest

Process showed that the program-control group means were significantly higher than those of the learner-control group.

## Discussion

Consistent with other observations (e.g., Lester, 1985), young children can be taught to use heuristic strategies in solving word problems. In the current study, subjects in the self-generated group were able to draw and use visuals for solving the word problems and in so doing, increased their performance. Other studies (Canner, 1979; Nelson, 1974; Yancey, 1981) have shown similar observation. The process of generating their own visuals was a more effective strategy than being supplied with visuals as shown by the higher posttest scores of the self-generated group. The active process of generating visuals took a longer time, but once the strategy was learned, it was applicable even after a delay of one week.

While past studies on learner control in CBI indicated that young students tend to terminate instruction too early if allowed (Tennyson & Buttery,1980), that was not the case here. After solving six word problems, subjects could have stopped but instead, they continued and opted for additional word problems. There are a number of possible factors that could account for this result. First, most of the subjects had limited experience with CBI and the novelty of working with the computer might have prompted them to ask for additional problems. Second, subjects might have believed that problem solving exercise was similar to rote learning and opted for more practice. Third, cultural and social factors could influence the subjects to attempt more problems. Numerous cross-cultural studies have indicated that Asian students (e.g., Japanese and Taiwanese) are more positive toward school learning (Walberg, Harnisch, & Tsai, 1986) and spend more hours on homework and on after-school instruction (White, 1985; Walberg et al., 1986). Social factors such as parental support and cultural emphasis on education have been cited as the main contributors to the higher mathematics achievement of Asians

(Miura, 1987). Perhaps, these factors could influence subjects to attempt more problems believing that attempting more would increase their performance.

While it is important for students to develop metacognitive skills in problem solving (e.g., Lester, 1985) , subjects in this study were unable to do so on their own, as reflected by the lower mean scores of the learner-control group. Subjects in the learner-control group attempted more problems and had more exposure to instructions. However, during the lessons, subjects were not told to "learn" from the prototype solutions. It was assumed that subjects would learn and benefit from the extra instruction when they saw the prototype solutions. The assumption was wrong. Other findings have also shown that young students when left on their own, were unable to generate their own learning strategies (e.g., Biehler and Snowman, 1986).

## Conclusion

The results of this study suggest that requiring students to generate their own visuals could be an effective strategy for solving word problems. Although Asian students may show different learner control patterns in computer-based instruction, students need more guidance to use extra exposure of instructional materials to their advantage.

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Figure 1

Screen Display: Visual-supplied Treatment

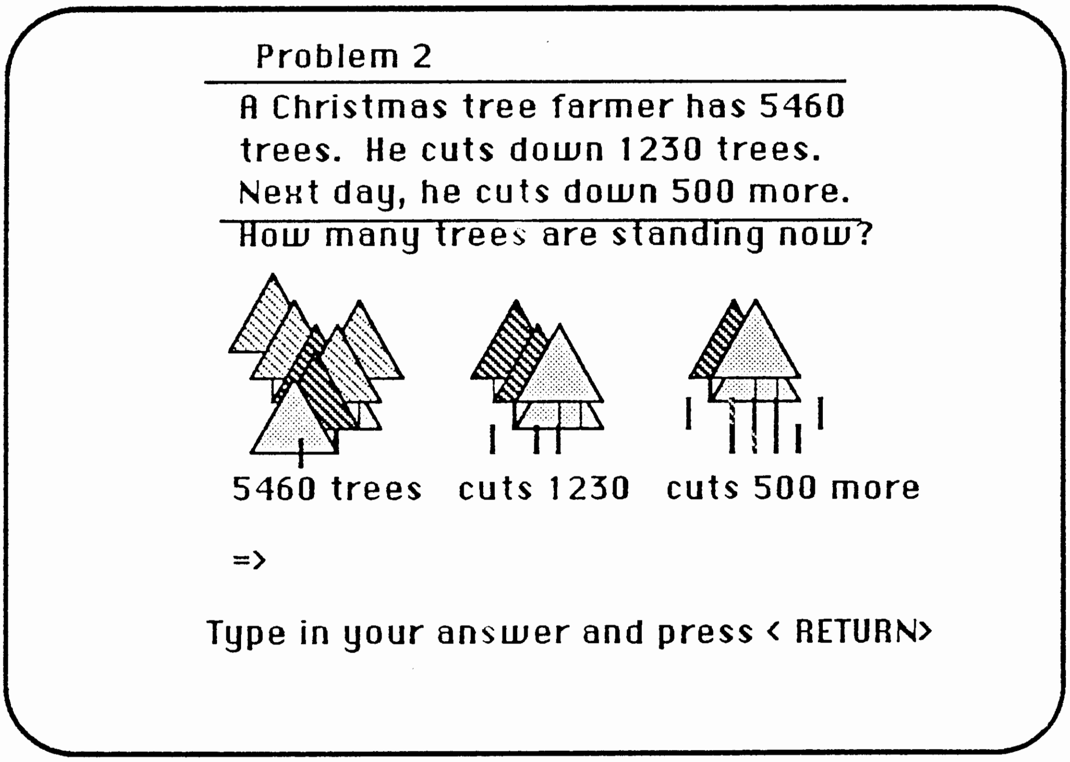

Figure 2

Screen Display: Selection of Process Operations

Problem 2

A Christmas tree farmer has 5460 trees. He cuts down 1230 trees. Next day, he cuts down 500 more.

How many trees are standing now?

Choose only 1 method.
Type a, b, c, d, or e and <RETURN>

a. 5460 - 1230 then subtract 500
b. 5460 - 1230 then add 500
c. 5460 + 1230 then subtract 500
d. 5460 -1230 then multiply 500
e. 5460 + 1230 then add 500

=>

Table 1

Pearson Correlation Coefficients

| | COMP | SV | On-Task Answer | On-Task Process | Posttest Answer | Posttest Process |
|---|---|---|---|---|---|---|
| READ | .46** | .22* | .17* | .21* | .37** | .41** |
| COMP | | .35* | .29** | .26** | .51** | .47** |
| SV | | | .30** | .38** | .46** | .41** |
| On-Task Answer | | | | .64** | .27** | .31** |
| On-Task Process | | | | | .42** | .45** |
| Posttest Answer | | | | | | .91** |

*$p < .05$. **$p < .005$

Table 2

Means and Standard Deviations for correct answers and process during On-Task lessons.

| | | Treatment | | | | | |
|---|---|---|---|---|---|---|---|
| | | No visual | | Visual-supplied | | Self-generated | |
| | | **Ans** | **Proc** | **Ans** | **Proc** | **Ans** | **Proc** |
| **Learner** | M* | 4.81 | 7.33 | 7.19 | 7.81 | 6.10 | 8.57 |
| **Control** | SD | 2.01 | 2.58 | 3.31 | 3.28 | 2.38 | 2.71 |
| **Program** | M ** | 3.95 | 5.38 | 4.62 | 6.43 | 3.95 | 5.76 |
| **Control** | SD | 2.01 | 2.33 | 3.31 | 2.18 | 2.38 | 2.34 |

* maximum possible = 16

** maximum possible = 10

Table 3

Means and Standard Deviations for correct answers and process for POSTTEST

| | | Treatment | | | | | |
|---|---|---|---|---|---|---|---|
| | | No visual | | Visual-supplied | | Self-generated | |
| | | Ans | Proc | Ans | Proc | Ans | Proc |
| Learner | M | 3.10 | 5.24 | 2.48 | 3.90 | 5.67 | 7.52 |
| Control | SD | 2.95 | 3.99 | 2.20 | 2.91 | 4.19 | 3.61 |
| Program | M | 4.57 | 6.48 | 4.33 | 6.19 | 4.90 | 7.24 |
| Control | SD | 3.44 | 3.59 | 3.21 | 3.46 | 3.11 | 3.60 |