DOCUMENT RESUME

ED 293 698		SE 049 038
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TITLE	A Computerized Training Procedure for Solving Arithmetic Word Problems with the Aid of Visual Schemes.	
PUB DATE	Sep 87	
NOTE	18p.	
PUB TYPE	Reports - Descriptive (141)	
EDRS PRICE	MF01/PC01 Plus Postage.	
DESCRIPTORS	*Computer Assisted Instruction; Computer Uses in Education; Elementary Education; *Elementary School Mathematics; *Learning Disabilities; Mathematics Curriculum; Mathematics Education; *Mathematics Instruction; Problem Solving; *Word Problems (Mathematics)	
IDENTIFIERS	*Visual Representation	

ABSTRACT

A training procedure was developed to improve (or to encourage) the construction of a meaningful problem representation by mentally retarded and learning disabled children. Children are taught to use an external visual representation for arithmetic word problems, in which the meaning of the problem is reflected. The construction of this visual pattern is supported by several tools. The tools enable the child to represent the (known) quantities or to manipulate quantities (or sets) to model the action(s) or relationship(s) described in the problem. For the construction of the visual pattern the child is offered a supply of icons, from which visual building blocks can be moved to a worksheet. Other 'soft-keys' make it possible to indicate the desired placement of sets, to erase (part of) the visual configuation or to indicate that feedback is requested. The user-interface allows the child to touch only the screen. As such, the present state of the problem solving route of the child at any moment during the training session is known and therefore may be interpreted and evaluated. The computer program is structured to such a degree that the progression through the trial is impossible unless all preceding steps have been completed correctly. (Author/PK)

ED293698

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'A COMPUTERIZED TRAINING PROCEDURE FOR SOLVING ARITHMETIC WORD PROBLEMS WITH THE AID OF VISUAL SCHEMES'.

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Poster for the EARLI conference 1987.

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Abstract

A training procedure has been developed to improve (or to encourage) the construction of a meaningful problem representation by mentally retarded and learning disabled children. These children are taught to use an external visual representation for arithmetic word problems, in which the meaning of the problem text is reflected.

The construction of this visual pattern is supported by several tools. These enable the child to represent the (known) quantities or to manipulate these quantities (or sets) to model the action(s) or relationship(s) described in the problem text. For the construction of this visual pattern the child is offered a supply of icons, from which visual building blocks can be moved to a work-sheet.

Other 'soft-keys' make it possible to indicate the desired placement of sets, to erase (part of) the visual configuration or to indicate that feedback is requested. The user-interface allows the child to touch only the screen. As such, the present stage of the problem solving route of the child at any moment during the training session is known and therefore may be interpreted and evaluated. The computer program is structured to such a degree that the progression through the trial is impossible, unless all preceding steps have been completed correctly.

Thusfar, no experience has been obtained with the computerized training program. However, a comparable pilot study with mildly retarded children, in which a human trainer replaced the computer coach, revealed positive results (van Lieshout & Jaspers, paper EARLI 1987).

'A COMPUTERIZED TRAINING PROCEDURE FOR SOLVING ARITHMETIC WORD PROBLEMS WITH THE AID OF VISUAL SCHEMES'

1. Introduction

Interest in the field of information processing has stimulated recent research of the semantic processes, involved in the interpretation of a verbal problem (Carpenter & Moser, 1982; Heller & Greeno, 1978; De Corte & Verschaffel, 1982).
Heller & Greeno (1978) proposed a model in which the semantic processing of word problems is viewed as a crucial component for solving verbal problems.
A problem solver firstly should construct an internal semantic representation of the problem statement to be able to understand and solve word problems. This requires the identification of the relevant elements and relations between these elements described in the problem text. With experience, conceptual as well as procedural knowledge are stored in memory as cognitive schemes. As such, an experienced problem solver activates one of these schemes and installs the relevant components and relations in this scheme. ('top down processing').
A novice problem solver does not yet possess these schemes and so is forced to build a representation 'bottom up'. This could imply that for novices to be able to solve word problems correctly, the careful analysis of the problem text is even more crucial than for experts. However, some literature suggests that children with learning disorders do not orientate on the problem and respond very impulsively when confronted with story problems. In his investigation of verbal problem solving skills of educable mentally retarded children, Goodstein a.o. (1971, 1972) found that these children tended to perform a mathematical operation randomly, mostly on all the numbers mentioned, irrespective of the relevance of the number. In general these children did not seem to actively analyze the problem text. According to Hall (1980), they lack the problem solving strategies as well as the planning skills needed to solve problems. In the absence of meaningful problem solving procedures, these children tend to use various strategies at will. Generally, their approach to word problems is not based on the problem structure. Instead they often focus their attention on 'key' words mentioned in the problem text and use these to select a mathematical operation (De Corte & Verschaffel, 1982).
Furthermore, children with learning disorders tend to answer verbal problems very quickly, lacking a preceding orientation on the problem statement. Indeed, children with poor performance in word problem solving do not read the whole text, and often do not even look at the question or tend to select just the numbers contained in the problem (De Corte & Verschaffel, 1986).

However, research of remedial teaching of children with learning disorders suggests that these children can be trained to apply a correct problem solving strategy by making them aware of the successive steps in the problem solving route. In this respect, Brown, Campione & Day (1981) point out the necessity of a structured approach, whereby these children should make each step of learning explicitly. These children should not only be instructed how to use a specific strategy, but also how to employ, monitor, check and evaluate that strategy.

Although much research in the field of word problems has been undertaken, as far as we know, training programs based on these theoretical models have not been developed yet. This may partly be explained by the fact that in the postulated models, it's not explicated how a problem representation is built from the problem text. The use of external representations to build physical models of the problem text could be considered. Investigations of children's initial solution processes have shown that even Kindergarten children, without having received any formal instruction, are extremely successful in the solving of the easier story problems. In general, these children tend to focus on the semantic structure of word problems and liberally use their fingers and cubes to represent the known sets of a word problem to model the actions or relationships described. As a matter of fact, these children use a variety of concrete modeling strategies determined by the semantic problem type (Carpenter, Hiebert & Moser, 1981; De Corte & Verschaffel, 1982).

Semantic analysis of word problems resulted in a distinction of four broad classes: change, combine, compare and equalize problems (Heller, 1979). Equalize problems are left out of consideration.

The following three problems illustrate the kind of distinction drawn between problem types:

(1) John had 3 cookies. He got some more cookies. In the end John has 8 cookies. How many cookies did John get? (change)

(2) Together John and Mary have 8 cookies. John has 3 cookies. How many cookies does Mary have? (combine)

(3) John has 3 cookies. Mary has 8 cookies. How many more cookies than John does Mary have? (compare)

Although all three problems can be solved by subtracting 3 from 8. (8 - 3 = .), children use a different strategy to solve each problem.

To solve the first problem, most children would construct a set of 3 cubes and subsequently add cubes to this set until it contained a total of 8 cubes. By counting the added cubes , the answer would be found. On the other hand, the second problem would be solved by constructing a set of 8 cubes, removing 3 of them and counting the

remaining cubes will give the answer. Finally, the third problem generally is solved by first constructing a set of 3 cubes, then constructing a set of 8 cubes in an one-to-one correspondence with the first set ('matching'). By counting the not matched cubes of the second set, the answer would be found.

It seems that these children do not regard 'addition' and 'subtraction' as abstract operations to be used for the solving of various problem types, but instead define these mathematical operations in the context of the problem type at hand.

As they grew older, most children develop an abstract vision of 'subtraction' and 'addition'.

It seems that insightful problem solving is based on the semantic analysis of word problems. Semantic analysis in particular forces children to consider the basic relations between the known and unknown quantities of word problems. Therefore, concrete modeling is hypothesized to predict the teaching of a successful problem solving strategy.

Thusfar, to our knowledge no research has been done to investigate the concrete modeling strategies (if any!) of children with learning disorders.

It's not certain whether these children ever had the problem solving strategies (such as modeling with materials or fingers), to the same degree as regular young elementary school children apparently have. These retarded children may as well have lost a major part of them (e.g. after first grade extrance and receiving formal instruction). If some type of quantitative representation as young competent problem solvers seem to use, results in an appropriate problem solving procedure, then it seems worthwile to investigate the possibility to teach the construction of external representations. The construction of a physical model could aid in memorizing as well as in the activation and storage of cognitive schemes. Therefore, a research program was started to investigate the possibilities for improving the word problem solving of children with learning deficiences by teaching them to make an external representation of the problem. It was also decided to investigate the usefulness of computer assisted instruction to monitor and correct the problem solving behavior of the child.

2. Description of the computer program

2.1. Overview

A computerized training program has been developed that allows children to use graphics on a micro-computer connected to a touch-screen monitor rather than to use physical objects to solve word problems. Children are taught to construct a visual representation with the aid of visual building blocks. The child is supposed to construct a specific visual model for each problem type used. These requested models are based

on the concrete modeling strategies used by most young competent problem solvers. As earlier studies have shown, the ease with which the answer set can be located determines to an important degree the probability of answering the problem correctly (Riley, Greeno, & Heller, 1981; Verschaffel, 1984; Ibarra & Lindvall, 1982). Therefore, a different color to represent sets must be used in this program if the joining of sets results in severe difficulty in marking off the answer set.

The construction of this visual pattern is divided into several steps:

1. the reading of the problem text,
2. the construction of a first set (of visual blocks),
3. determined by problem type:
   * addition of a second set, or
   * division of the first set in two different sets, and
4. identifying the answer set.

For the construction of this visual pattern, the child is offered a supply of 'icons', from which visual building blocks can be moved to a work-sheet. Other 'soft-keys' make it possible to indicate the desired placement of sets, to erase (part of) the visual configuration or to indicate that feedback is requested.

Depending on the correctness of the visual arrangement of the blocks, the child is allowed to continue the construction of this visual pattern or to correct this configuration. In case a mistake is made and if the child fails on two successive occasions as well, the requested visual configuration of building blocks is depicted by the computer.

The computer program is structured to such a degree that the progression through the trial is impossible, unless all preceding steps have been completed correctly.

Besides, the child is not allowed to return to a previously performed step. Passing through all the steps of the trial results in a visual representation, in which the answer set can be located easily. Once the correct answer is given, either by the child or the computer, the child is allowed to solve the next word problem.

At any moment during the training session, the present stage of the problem solving route of the child is known and therefore can be interpreted and evaluated.

2.2. *Details of the computer program*

The major feature of the computer program is the ability to enter into the touch screen monitor visual configurations by touching appropriate soft-keys on the monitor. Touching the screen results in an XY-coordinate that is sent back to the computer which indicates the area on the screen that was touched. As such the child is freed from pressing keys on a keyboard. In particular for children with learning disorders, typing

answers and looking alternately at the screen and keyboard might increase the mental processing load, and consequently disturb the problem solving process.
Simply touching soft-keys on a screen might compensate these difficulties.
The video-screen is divided in four main areas: (see figure 2)

1. the upper part of the screen is reserved for the projection of the problem text.
2. the soft-keys are presented on the second upper part of the screen, the 'icon-supply'. These soft-keys exist of:
   * two rows of 9 visual building blocks distinguished by color.
   * two separate blocks (one black, one white) with a cross.
   * three distinct arrows with four small blocks.
   * two distinct arrows with one small block.
   * a READY key.
   * an ERROR key.
3. the feedback is presented on the third area of the screen.
4. the lower part of the screen is used as work-sheet.

At the start of the computer program only the problem text and the READY soft-key are depicted on the screen (fig.1). First, the child is encouraged to read the problem text carefully. After reading the text, the child has to announce he has completed this step by touching 'READY'. Touching 'READY' within 10 seconds results in the command to read the text carefully once more . Finally, all soft-keys appear on the appropriate places and the screen looks much like figure 2.
Now, the child is supposed to construct the first set (step 2). The touching of visual building blocks successively in either row results in the moving of these blocks from the icon-supply to the work-sheet. The blocks that represent the first set are always moved to the upper left corner of the work-sheet. Once a building block of a specific color has been moved, it's impossible to move blocks of the other color to represent this particular set. Touching a different colored block results in feedback that points out why this specific response is not permitted. The same fact holds for touching the arrows in step 2, as well as touching 'ERROR' without the presence of blocks on the work-sheet. Otherwise, touching the ERROR soft-key results in the replacement of all blocks that were moved in this particular step into the icon-supply and the child is allowed to start all over again. Putting blocks back into the icon-supply one by one can be accomplished by touching the crossed square of the appropriate color.
After completion of the construction of the first set or in case the child does not remember which action to perform, it has to announce, by touching 'READY', that feedback is requested. If the constructed configuration resembles the requested configuration, the computer confirms the correctness of the configuration. Otherwise, a 'hint' concerning the mistake is given for correct execution of the step.

In general, the modeling behavior in step 2 might deviate from the requested modeling behavior in three aspects:

* the number of visual building blocks moved to the work-sheet does not agree with the expected number ('wrong number')
* the selected color of visual building blocks does not match the required color ('wrong color'), and
* a combination of both.

For example, if the child moves a wrong number of building blocks to the work-sheet, the computer replies: "The number of moved blocks is not right. Read the text again and move the right number of blocks". This is followed by clearing the work-sheet and offering a second and third opportunity. Whenever the same incorrect action (e.g. 'wrong number') is undertaken on this attempt, the second level feedback is given, ("LOOK AGAIN CLOSELY AT THE TEXT') and the part of the problem text, that represents the relevant set, is highlighted (e.g. 'Peter had 8 marbles').

On the other hand, the modeling behavior of the child on this second occasion might also deviate from the requested visual model in another respect. For example, his first mistake can be 'wrong number', whereas on this second occasion, the requested number of blocks could have been moved to the work-sheet, but a 'wrong color' is used to represent the set. In this case, the first level feedback based on wrong color usage is given on this second occasion (N.B. the first and second level feedback is the same for 'wrong color', namely: "The number of blocks is correct, but you should use black blocks instead". This is followed by offering a third opportunity. Whenever the child fails on this occasion, the relevant parts of the text are highlighted once more and the requested configuration is shown by the computer. Once the construction of a set is completed correctly, either by the child or the computer, the child is no longer allowed to affect this configuration except for the separation of blocks from set 1 in step 3, (described later).

Thus, the feedback presented during the execution of a particular step differs from the feedback after completion of a step in respect of its significance. Whereas feedback based on wrong soft-key usage merely explains why the touching of a specific soft-key is not logical for the moment, the feedback presented after completion of a step points at the correctness of the execution of a specific step.

Subsequently the child is supposed to execute step 3. The structure of step 3 is similar to the previous one, except that the child now has to decide if more building blocks are to be moved to complete the configuration (a second set) or if building blocks from set 1 are to be separated. By this time, all 'arrow keys' are 'touch-sensitive'.

The three arrows with four small blocks can be used to indicate the desired placement of set 2 (<-□□=added to set 1, □□-> = held at a distance from set 1, □□□↓ =

placed in one-to-one-correspondence with the building blocks of set 1). If the child decides to separate blocks from set 1, the two arrow keys with one small block can be used. Touching of ▫-> results in one block separated from set 1, touching of <-▫ results in the replacement of the block last moved to set 1.

Touching the 'ERROR' key during execution of step 3 might either result in:

1. the replacement of the building blocks that were moved <u>in step 3</u> into the icon-supply.
2. the replacement of all building blocks separated from set 1 back to their starting position in set 1.

In both instances, this means that the child is allowed to execute step 3 all over again starting from the configuration constructed in step 2. Also, blocks can be moved back into the icon-supply one by one by touching the crossed square with the right color. Completion of this step by the child again has to be affirmed by touching 'READY'. Now, the model constructed might deviate in two additional respects compared to step 2:

* the placement of the visual blocks added to the former configuration doesn't correspond with the requested placement.
* visual building blocks are added whereas visual building blocks should be separated from the former configuration (or the other way round).

Again, two other opportunities are offered to correct a wrong visual configuration. Once more, 'similar' mistakes on this second and third occasion result in the computer highlighting the relevant text and commanding: "LOOK ONCE MORE CLOSELY AT THE TEXT". On the third occasion this is accompanied by the computer depicting the correct visual model. Otherwise, a mistake, that differs with respect to the mistake made in the first attempt is followed by the first level feedback for this particular mistake. Erring on the third and final attempt regardless of the sort of mistake made results in the same feedback procedure as described before.

Finally, the child is supposed to identify the answer set by pointing at the relevant blocks in step 4. At that time, all the blocks that form part of the final configuration on the work-sheet are 'touch-sensitive'.

Touching a visual building block in this configuration results in the flashing of this block. Two different mistakes (or a combination of both) can be made in completing step 4.

* the amount of building blocks pointed at does not agree with the requested amount.
* the location of blocks pointed at does not agree with the real location of the answer set.

Once the child finishes this step by touching 'READY', the computer evaluates the response of the child by comparing the building blocks that were touched with the requested amount and position of blocks to be touched. Correctly completing step 4

results in the computer responding: "Very good, go on with the next problem". Otherwise, the computer provides a 'hint'. For example, in case mistake 2 is made: "WHERE are the blocks to be pointed at located?" Again, a second and third opportunity is presented to the child. Erring on both occasions leads to the computer replying: "These are the blocks to be touched" and flashing of the blocks that had to be touched. In both instances, the next problem is presented and the procedure described starts all over again.

2.3. System configuration

The computer program was written in Apple UCSD-Pascal, version 1.3, using the Pascal turtlegraphics utility to animate the soft-keys and to project text with the aid of the bigger letters delivered by the Apple Pascal characterset. It requires an Apple II e microcomputer with 128Kb (Extended 80 columns card), a Thunderclock Plus Clock Card as timing device, and a Philips VP 120 touch-screen monitor. The Philips VP 120 consists of a color t.v. monitor with a touch panel which fits over the televisionscreen. The touch-panel emits infra-red light beams in front of the monitor screen. Touching the screen causes an interruption of the light beams and results in an XY-coordinate sent back to the computer which indicates the area on the screen that was touched. The hardware-interface between the Philips VP 120 and the Apple computer is provided by an Apple Super Serial Card. An (UCSD) assembler-routine has been written for the software-interface.
Future versions of the training procedure will be written in TML Pascal for Apple II gs.

3. Concluding remarks

Thusfar, no experience has been obtained with the computerized training program. A primary experiment has just started. However, comparable pilot studies with mildly retarded children, in which a human trainer replaced the computer coach, revealed positive results (Van Lieshout & Jaspers, paper EARLI 1987; Jaspers, 1987). These children seemed to benefit from a training procedure, whereby they were instructed on modeling behavior (De Corte & Verschaffel, 1982; Carpenter & Moser, 1981; 1982). Young children seem very able to solve word problems if they are allowed to use a model for representing these problems, this correspondends with earlier studies.
However, the subjects in the pilot-study weren't permitted to construct their own material representation of a word problem, but instead their representation had to resemble the model instructed. This was decided for reasons discussed in the Introduction. The overall results concerning the execution of steps revealed the effectiveness of this algorithmic procedure. The mildly retarded children in the pilot-

study were able to handle the instructed configurations, in view of the overall increase in the number of correctly executed steps. The results of this pilot-study illustrate the capacity of a computer assisted training procedure for teaching mildly retarded children to solve word problems. In particular, the surplus value of a computerized training procedure could manifest itself in several respects. For example, the literature with regard to CAI indicates that erring during a computerized exercise is not experienced as being as unpleasant as failing in presence of a human teacher. Secondly, training humans in practicing a complex training procedure is very time-consuming and even then, procedural mistakes are easily made. Finally, daily school practice doesn't permit a teacher to spend much time with an individual child for economical reasons.

Past experiences with a touch-screen device already revealed its usefulness with learning disabled and mildly retarded children (Van Lieshout & Anbeek, 1986; van Lieshout, 1987). Simply pointing at soft-keys on the screen instead of using a keyboard for typing answers is immediate and natural and therefore might be accompanied by a reduction in processing demands, followed by a reduction in data entry errors. In assessing the effectiveness of various response-media, Beaumont (1985) already reported a clear superiority in speed of response for the touch-screen as opposed to the standard QWERTY keyboard, a numeric keypad and a lightpen.

On the condition that similar training procedures will be so much structured so as to perceive and record every phase of the on-going problem solving process, thereby allowing this process to be influenced, touch behavior in revealing this process seems an adequate mode of responding.

Figure 1: Screen display at the start of each problem statement in a trial (step 1).

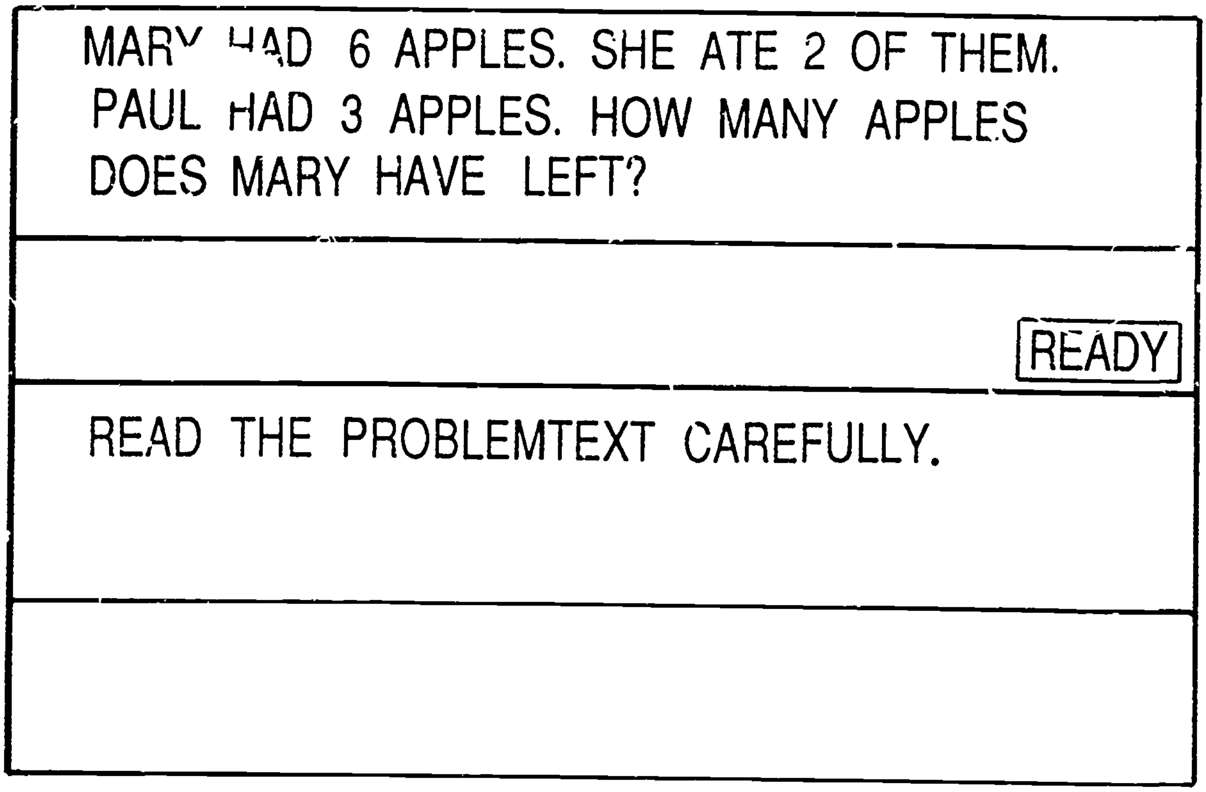


Figure 2: Screen display at the start of the execution of step 2.

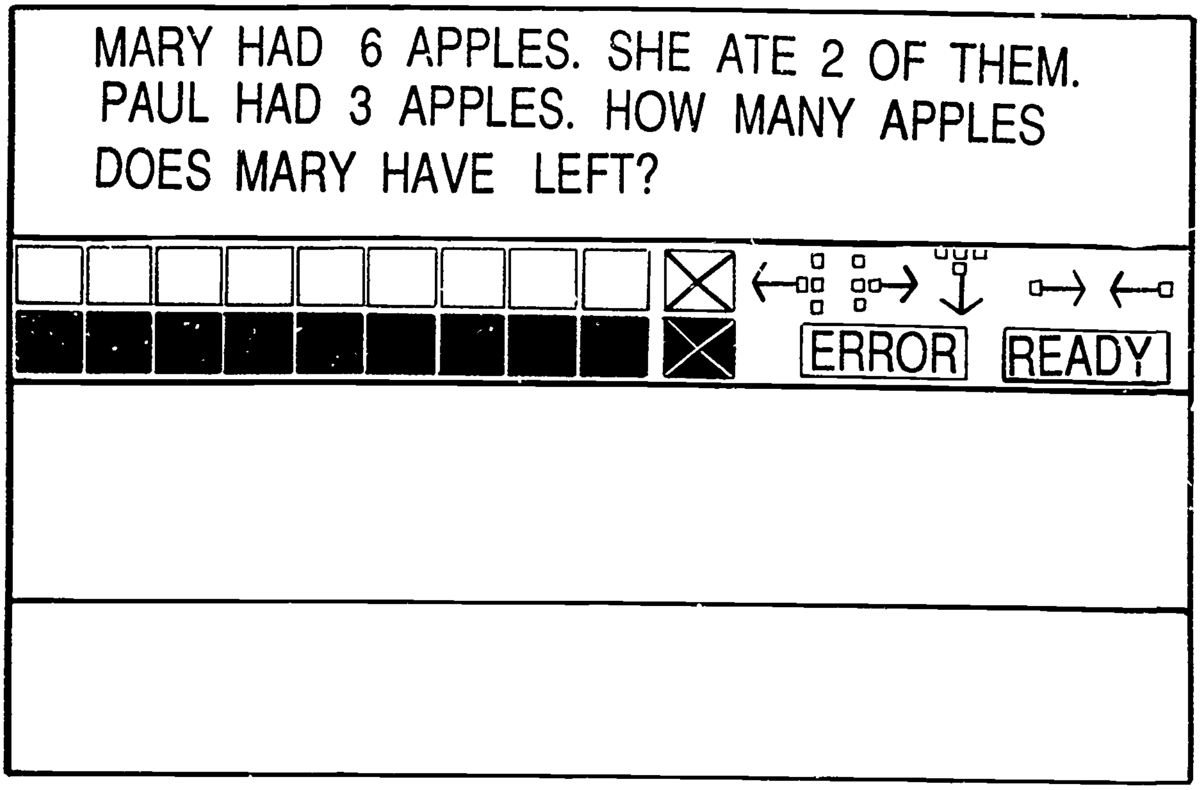


Figure 3: An example of a screen display during the execution of step 2.

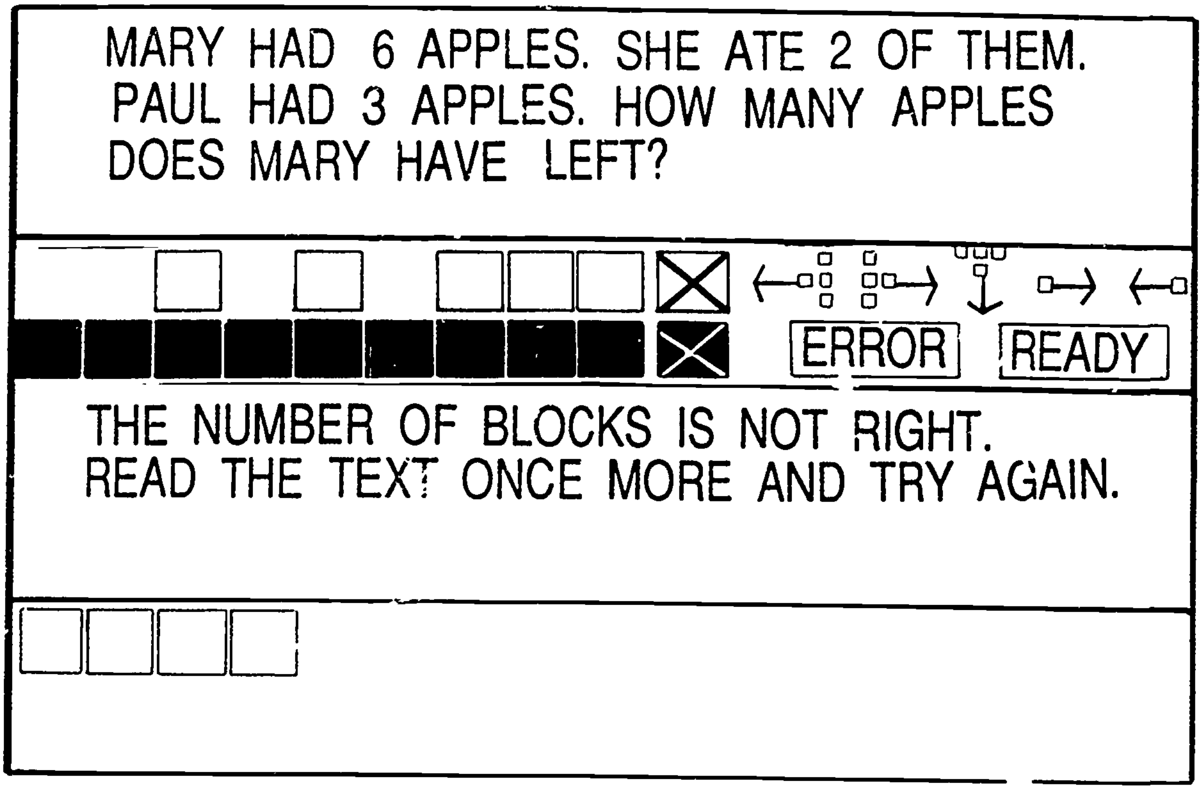
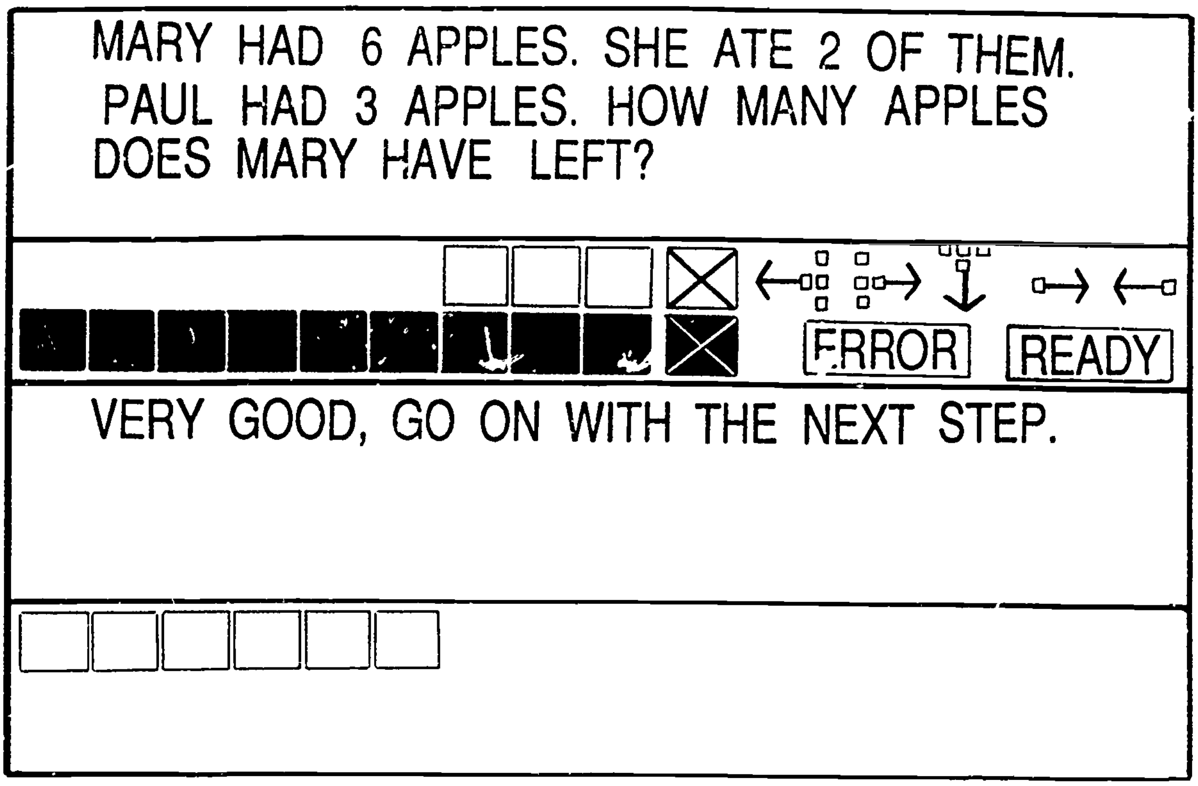


Figure 4: An example of a screen display after completion of step 2.



change 2: Mary had 6 apples. She ate 2 of them. Paul had 3 apples.
How many apples does Mary have left?

change 3: Mary had 2 apples. She got some more. Paul had 3 apples. Now Mary has 6 apples.
How many apples did Mary get?

change 4: Mary had 6 apples. She ate some of them. Paul had 3 apples. Now Mary has 2 apples.
How many apples did Mary eat?

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combine 1: Mary has 2 apples. Peter has 4 apples. John has 3 apples.
How many apples does Mary and Peter have together?

combine 2: Mary has 2 apples. Peter also has some apples. John has 3 apples. Together Mary and Peter have 6 apples.
How many apples does Peter have?

combine 3: Together Mary and Peter have 6 apples. Mary has 2 apples. John has 3 apples.
How many apples does Peter have?

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compare 1: Peter has 2 apples. John has 3 apples. An has 8 apples.
How many more apples than Peter does An have?

compare 2: Peter has 2 apples. John has 3 apples. An has 8 apples.
How many apples less than An does Peter have?

compare 3: Peter has 2 apples. John has 3 apples more. An has 6 apples more.
How many apples does An have?

compare 4: Peter has 8 apples. John has 3 apples less. An has 2 apples less.
How many apples does An have?

Table 1: Examples of word problems used in the pilot-study.

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