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Training Strategies for Attaining Transfer of Problem-Solving Skill in Statistics: A Cognitive-Load Approach

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In statistical problems, the differential effects on training performance, transfer performance, and cognitive load were studied for 3 computer-based training strategies. The conventional, worked, and completion conditions emphasized, respectively, the solving of conventional problems, the study of worked-out problems, and the completion of partly worked-out problems. The relation between practice-problem type and transfer was expected to be mediated by cognitive load. It was hypothesized that practice with conventional problems would require more time and more effort during training and result in lower and more effort-demanding transfer performance than practice with worked-out or partly worked-out problems. With the exception of time and effort during training, the results supported the hypotheses. The completion strategy and, in particular, the worked strategy proved to be superior to the conventional strategy for attaining transfer.

Substantial evidence exists indicating that, in the empirical and formal sciences, such as mathematics, physics, and computer science, traditionally used instruction is not an effective learning device (Cooper & Sweller, 1987; Larkin, McDermott, Simon, & Simon, 1980; Sweller, 1988; Sweller, Chandler, Tierney, & Cooper, 1990; Tarmizi, & Sweller, 1988; Van Merriënboer, 1990; Van Merriënboer & De Croock, in press). In conventional instruction, the kernel of practice is formed by solving problems, the specification of which involves the description of an initial problem state and a goal state. Learners must apply a particular set of problem-solving operators to solve the problem and reach the goal state.

From expert–novice research, it has become clear that because of the absence of cognitive schemata, novices are compelled to use weak problem-solving methods, such as means–ends analysis, pure forward search, and hill climbing, when solving conventional problems in a new domain (Anderson, 1987). Especially for more complex domains, learning automated rules through compilation of weak-method problem solutions is a time-consuming and effortful process, which seems to inhibit the processing of aspects of the problem structure required for schema acquisition. Through a computational cognitive-load model and experimental evidence, Sweller (1988) showed that the means–ends strategy used by novices to solve conventional trigonometry problems left little processing capacity for such schema acquisition. A large amount of capacity was required for simultaneously considering and making decisions about the current problem state, the goal state, differences between states, and problem-solving operators to be used to reduce these differences.

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Both rule automation and schema acquisition may be seen as prerequisite cognitive processes for transfer of problem-solving skills (e.g., Cooper & Sweller, 1987; Jelsma, Van Merriënboer, & Bijlstra, 1990; Sweller, 1989; Van Merriënboer & Paas, 1990). Thus, in traditional instruction, transfer is often near, that is, limited to problems that are highly similar to the ones used during training. A *schema* can be conceptualized as a cognitive structure that enables problem solvers to recognize problems as belonging to a particular category of problems that require particular operations to reach a solution. Acquired schemata can provide analogies in new problem-solving situations and can be used in mapping processes to reach solutions for unfamiliar aspects of the problem-solving task.

Cognitive load is a multidimensional concept in which two components—mental load and mental effort—can be distinguished. *Mental load* is imposed by instructional parameters (e.g., task structure, sequence of information), and *mental effort* refers to the amount of capacity that is allocated to the instructional demands. Manipulations to increase mental load by way of instructional changes will only be effective if subjects are motivated and actually invest mental effort in them. In this study, the subjects' motivational state is expected to be high and equally divided across the experimental conditions. Therefore, the intensity of effort is considered to be an index of cognitive load.

In the present study, a rating scale was used to determine the perceived intensity of mental effort. The scale is a modified version of Bratfisch, Borg, and Dornic's scale (1972) for measuring perceived task difficulty. In their study a Spearman rank order correlation of 0.9 was obtained between objective and subjective task difficulty. Among others, Gopher and Braune (1984) have shown that subjects can introspect on their cognitive processes with no difficulty in assigning numerical values to the imposed mental load or the invested mental effort. The results of empirical and theoretical studies on scaling, performed by Borg and his colleagues (Borg, 1978; Borg, Bratfisch, & Dornic, 1971) suggest that the type of scale used is not critical; the choice of category scales, magnitude estimation, and the presence or absence of verbal labels makes little difference. Furthermore, subjective measures are easy to obtain, nonintrusive, easy to analyze, and have very high face validity (O'Donnel & Eggemeier, 1986).

In this study I compared the effectiveness, in performing statistical problems, of a *conventional strategy*, in which conventional problems are emphasized, with two alternative strategies, in which worked-out problems (*worked strategy*) and partly worked-out problems with a completion assignment (*completion strategy*) formed the kernel of the training. The alternative strategies were developed according to Sweller's (1988) cognitive-load theory, in which the distribution of cognitive resources forms an important aspect. According to Sweller's theory, raising the quality of practice problems in instruction can be attained by (a) minimizing the amount of cognitive capacity that is necessary for extraneous activities (any cognitive process that is not essential to attaining relevant goals) and (b) appropriately directing attention.

Because for novices problem-solving methods seem to be inextricably bound with problem form and because these methods determine the amount of cognitive capacity and time available for schema acquisition and practice, I assumed that practice-problem form would affect training performance and subsequent transfer performance. With regard to training performance, I hypothesized that the worked and completion conditions would require less mental effort and less instructional time than would the conventional condition.

The main hypothesis of this study was that subsequent transfer performance in the worked and completion conditions would be higher and less effort demanding than in the conventional condition. With regard to the worked strategy, this assumption was based on the work of Sweller and his colleagues (Cooper & Sweller, 1987; Sweller, 1988; Tarmizi & Sweller, 1988); with regard to the completion strategy, the assumption was based on the work of Van Merriënboer (1990) and Van Merriënboer and De Croock (in press).

Furthermore, data were collected on instructional time, mental effort invested in instruction, and number of incorrect solutions generated during instruction. Whereas no hypotheses were formulated with regard to these variables, the variables can be helpful for interpreting the results.

Method

Subjects

The participants were 46 students (45 male and 1 female), 16–18 years of age. They were recruited from two 2nd-year classes of a secondary technical school (Middelbaar Technische School [1]) in The Netherlands. The subjects participated as part of a business administration course. The transfer test was considered a formal school examination by the students.

Materials

The materials covered the domain of basic statistics (i.e., central tendency measures). The following topics were treated successively: arithmetic mean, median, and mode. After instruction, students were expected to have gained insight into the presentation of large amounts of data and were expected to be able to calculate the arithmetic mean, median, and mode for problems that are more (near transfer) or less (far transfer) similar to those encountered during instruction.

Three training programs were developed on a Macintosh IIcx computer with Authorware Professional (Authorware Inc., 1987). After the programs had been converted and implemented, the experiment was performed on XT-compatible MS-DOS computers. The instructional conditions differed from each other in the way in which they emphasized a certain type of practice-problem form. In the conventional, worked, and completion conditions, emphasis was placed on conventional problems (OPs), worked-out problems (WPs), and completion problems (CPs), respectively. The instructional prescriptions for these practice-problem forms were, respectively, to solve a problem, to study a problem solution, and to complete a partly worked-out problem solution.

Before the experiment started, the students received an explanation sheet containing general (procedural) information and scrap paper. Figure 1 shows the three consecutive stages of the experiment: general instruction, specific instruction, and test.

General instruction. In the general instruction stage, the theory of the measures of central tendency and the rating of the mental effort scale were explained.

Specific instruction. In the specific instruction stage, an identical set of 12 problems was presented in each condition. In order, 6 problems dealt with the arithmetic mean, 3 problems covered the median, and the final three problems were concerned with the mode. The problems were presented in subsets of 3, which were each preceded by some theory and an illustrative worked example. The form of the first 2 problems in each subset was determined by the experimental condition (conventional, OP_1–OP_8; worked, WP_1–WP_8; completion, CP_1–CP_8). The last problem of each subset was a conventional problem (OP_{1-4}). Thus, the form of these problems was condition independent.

Therefore, in the conventional condition, all problems had to be solved by the subjects; in the completion condition, the subjects had to complete the condition-dependent problems; and in the worked condition the subjects had to study the condition-dependent worked-out problems. In the latter two conditions, each third problem had to be solved.

Test. For all conditions the test consisted of the same 24 problems (OP_{5-28}). A priori, 12 problems were assigned a near-transfer and 12 a far-transfer characterization. In this study the relative terms of the near–far transfer continuum were considered within the domain of statistics. The classification depended on the similarity of the problem format to the training problems and was performed by the experimenter and approved by two experts (teachers in statistics). Except for specific values, the near-transfer problems resembled the conventional-training problems. The far-transfer problems were characterized by presentation formats that differed from the problems during instruction, involved unstructured data presentations, and required application of different combinations of problem-solving strategies. Figure 2 shows two examples each of instructional, near-transfer, and far-transfer problems.

Mental-effort rating scale. Subjects reported their invested effort on a 9-grade symmetrical category scale, by translating the perceived amount of mental effort into a numerical value. The numerical values and labels assigned to the categories ranged from *very, very low mental effort* (1) to *very, very high mental effort* (9). The scale was provided, explained, and illustrated to the students just before the beginning of the experiment and again during the general instruction.

In the present study, the reliability of the scale was estimated with Cronbach's coefficient alpha. For the condition-independent instruc-

[1] Middelbaar Technische Schools are Dutch schools that prepare students for applied technical occupations.

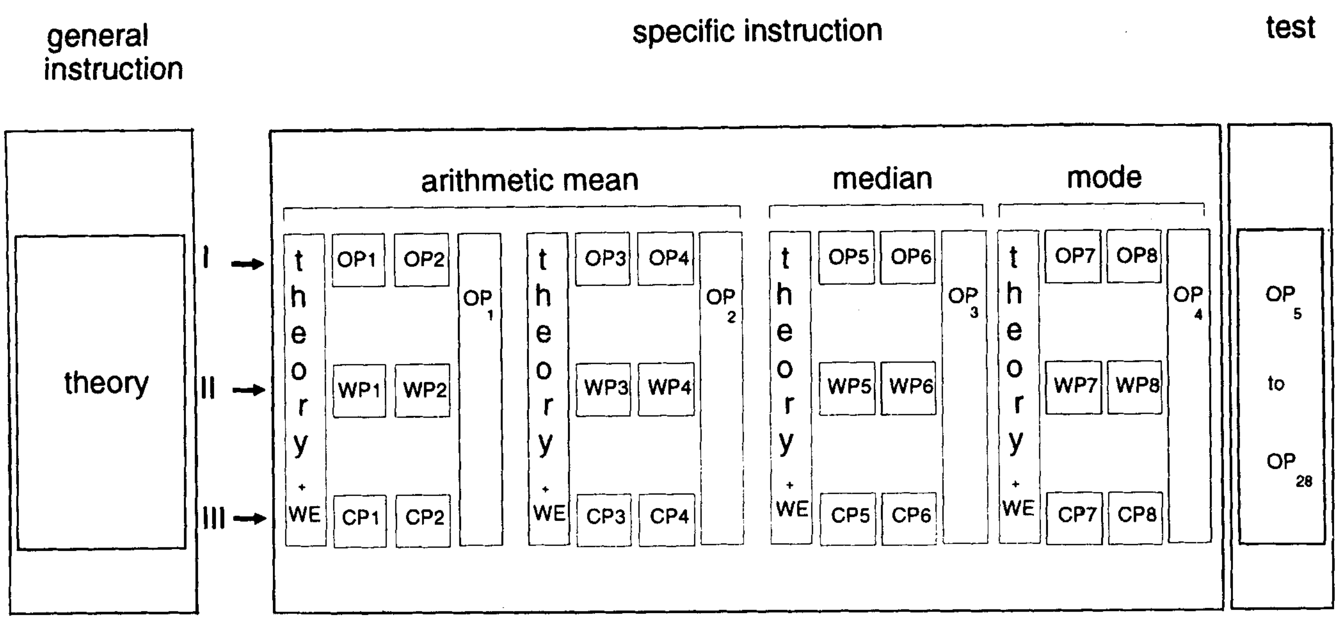


Figure 1. Schematic presentation of the procedure of the experiment. (WE = worked example; OP = conventional problem; WP = worked problem; CP = completion problem. Full size numerals represent condition-dependent problems, and subscript numerals indicate problem numbers for condition-independent problems. Both full-size and subscript numerals represent problem numbers, but all problems with subscript numbers were identical for each condition, whereas the problems with full-size numerals differed across conditions.)

Instructional problems

The table below shows the temperature (Celsius) at 3:00 PM on 5 days of July in the city of Enschede.

Day	1	2	3	4	5
Temperature	18	16	20	21	19

Calculate the mean temperature for this period.

A group of 56 students was tested on its knowledge of statistics. The range of the test was 0 to 10.
2 students had a 9
8 students had a 8
12 students had a 7
22 students had a 6
12 students had a 5

Calculate the mean grade.

Near-transfer problems

Calculate the mean for the following row of numbers:
13, 16, 16, 13, 13, 14, 12, 15, 25

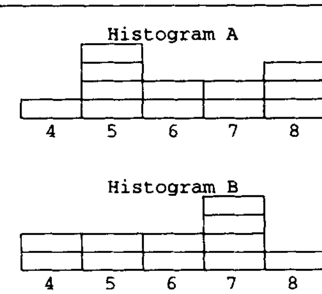
A group of students collected money for their football club.
125 persons each gave 25 cents
24 persons each gave 50 cents
32 persons each gave 75 cents

Calculate the mean amount of money each person gave.

Far-transfer problems

Which number is represented by X in the frequency table below, when it is known that the mean equals 5?

Number	Frequency
3	1
4	4
5	5
6	2
7	X



Which of the two histograms has the higher mean?

Figure 2. Examples of instructional, near-transfer, and far-transfer problem formats. (The problems were presented to the students in Dutch.)

tional problems and the test problems, a coefficient of reliability (α) of .90 was obtained.

Design and Procedure

The subjects were randomly assigned to one of the three conditions. In one session, all subjects were tested at the same time. Forty-five computers were available in two adjoining classrooms, so that the student–computer ratio was 1:1. At the beginning of the experiment, the subjects were told about the procedure of the experiment and presented with an explanation sheet. The computer-based training started after this verbal and written introduction.

The *general instruction* was presented at a pace that was partly student controlled and partly program controlled, that is, between a minimum of 0.5 min and a maximum of 5.0 min, the students could determine their own pace. The students were presented with information and three worked examples. They had the opportunity to study these examples until they understood the concepts, general procedure, and rules required to solve central tendency problems.

In the *specific instruction*, the students were asked to solve, complete, or study 12 problems. After each problem the student rated the perceived amount of mental effort invested in the problem. The students were allowed to work on each problem for a minimum of 0.5 min and a maximum of 5.0 min. After 5.0 min, or after the student had given three incorrect solutions, the program presented automatically a problem solution in a worked-out format, which could be studied for 3.0 min. Subjects in the worked condition were told that they should study each worked example until they were sure they understood the principle, because the next conventional problem that they were to solve would be similar. For $OP_{1\text{-}4}$ the boundaries for solution were set between 0.5 and 7.0 minutes. If the student was unable to solve the problem, or if three incorrect solutions were generated, the worked-out problem, for which the studying time was limited to 5.0 min, was presented.

Finally, students took a 24-problem *test*. The 12 near-transfer problems had to be solved first. A maximum of 40.0 min was allowed for the test. A subject could proceed with the next problem at any time, irrespective of the quality of the solution. No feedback was provided. As was the case during instruction, ratings of the perceived amount of mental effort, problem solutions, and problem-solving times were automatically registered by the computer.

Results

The data were analyzed with one-way analyses of variance (ANOVAs). Because of computer registration problems there were incomplete data from 4 subjects. This resulted in a sample of 13 subjects in the conventional condition, 14 in the worked condition, and 15 in the completion condition. Dependent variables were time on general instruction, time on specific instruction, number of incorrect solutions generated, time on test, test performance, and perceived amount of mental effort invested during specific instruction and during the test. In cases of significant F tests, I conducted post hoc multiple comparisons using Fisher's significant-difference procedure. The significance level for post hoc tests was set at $p < .05$.

Table 1 shows the mean time on task as a function of practice strategy. Subjects in the three groups spent the same amount of time on the general instruction, $F(2, 39) = 0.34$. The time spent on specific instruction differed across the three conditions, $F(2, 39) = 6.86$, $p < .01$, $MS_e = 55.54$. Students spent less time on the worked instruction problems than on the conventional or completion instruction problems, which did not differ in terms of time spent on problems. The amount of time spent on solving the condition-independent problems ($OP_{1\text{-}4}$) during training did not differ significantly across conditions: for OP_1, $F(2, 39) = 0.41$; for OP_2, $F(2, 39) = 0.30$; for OP_3, $F(2, 39) = 1.63$; and for OP_4, $F(2, 39) = 2.23$. With these solving times serving as a repeated measures variable in a two-way ANOVA, a test on trend was performed. The linear component of the interaction with condition was not significant, $F(6, 48) = 1.32$.

Table 1
Mean Time on Task (in Minutes) as a Function of Condition

Task	Condition		
	Conventional	Worked	Completion
General instruction	6.5	6.2	6.3
Specific instruction	42.5	32.3	39.8
OP_1	2.9	2.5	2.6
OP_2	2.4	2.8	2.4
OP_3	2.6	2.2	2.0
OP_4	8.0	6.5	7.1
Test	34.8	36.4	32.0
Near-transfer problems	22.1	19.8	18.8
Far-transfer problems	12.7	17.6	13.2

Note. OP = conventional problem. Subscrips represent problem numbers.

With regard to errors, it was not possible to make them on condition-dependent problems in the worked condition, and only calculation errors could be made on these problems in the completion condition. In the conventional condition, both calculation and procedural errors were possible. Although students were explicitly instructed to write down all the solution steps of a problem on their scrap paper, these data turned out to be too incomplete for drawing reliable conclusions on error types. Therefore, only data on the number of errors are presented.

The mean numbers of initially generated incorrect solutions on the 8 condition-dependent instructional problems of the conventional and completion conditions were 0.98 and 0.07, respectively. Students in the conventional condition generated significantly more incorrect solutions than students in the completion condition, $t(26) = 5.95$, $p < .001$.

The mean numbers of initially generated incorrect solutions on the 4 condition-independent instructional problems of the conventional, worked, and completion conditions were 0.80, 0.46, and 0.41, respectively. An ANOVA showed that these means did not significantly differ, $F(2, 39) = 1.28$.

The time spent on the transfer test was the same for all conditions, $F(2, 39) = 2.08$. A more detailed look at the data showed that the time spent on the near-transfer problems, as well as the time spent on the far-transfer problems, did not differ across conditions: $F(2, 39) = 2.95$, and $F(2, 39) = 2.35$, respectively.

Table 2 provides a view of the mean test scores as a function of practice strategy. The ANOVA performed on the transfer-test scores showed that the total number of problems answered correctly differed across conditions, $F(2, 39) = 13.55$, $p < .001$, $MS_e = 10.57$. Multiple comparisons showed that the conventional condition yielded the lowest scores. The scores of worked and completion conditions were at the same high level. A closer look at the data revealed significant condition effects for performance on both the near-transfer problems, $F(2, 39) = 6.17$, $p < .01$, $MS_e = 1.85$, and the far-transfer problems, $F(2, 39) = 8.32$, $p < .001$, $MS_e = 8.87$. Multiple comparisons revealed superior near-transfer performance in the worked condition. Near-transfer performance in the conventional and completion conditions did not differ. With regard to far-transfer performance, the scores in the conventional condition were lower than the scores in the worked and completion conditions, which were at the same high level.

Table 3 shows the mean amount of perceived mental effort as a function of practice strategy. Apparently the processes required to work during specific instruction demanded the same amount of mental effort in all conditions, $F(2, 39) = 0.74$. The mental effort data for solving OP_{1-4} was likewise the same: for OP_1, $F(2, 39) = 0.10$; for OP_2, $F(2, 39) = 1.43$; for OP_3, $F(2, 39) = 0.34$; and for OP_4, $F(2, 39) = 1.83$.

The perceived amount of mental effort invested during the transfer test differed across conditions, $F(2, 39) = 17.79$, $p < .001$, $MS_e = 0.67$. Post hoc tests showed that the perceived amount of mental effort invested in the conventional condition was higher than that invested in the worked and completion conditions. If these data are differentiated for near and far transfer, the results reveal the same tendency: $F(2, 39) = 9.14$, $p < .001$, $MS_e = 1.01$, and $F(2, 39) = 14.97$, $p < .001$, $MS_e = 1.00$, respectively.

Discussion

The results of this study support the hypothesis that a cognitive structure resulting from instruction emphasizing practice with partly or completely worked-out problems is a more efficient knowledge base for solving transfer problems than one resulting from instruction emphasizing conventional problems. Training with partly or completely worked-out problems leads to less effort-demanding and better transfer performance. Moreover, time on training was shortest in the worked condition.

The finding that the absolute mental-effort data during instruction did not differ across conditions complies with the assumption of equally divided motivation. With regard to mental effort during transfer, the results are in accordance with an efficiency view of learning (Ahern & Beatty, 1979). This view is consistent with the notion that the component processes of any task might individually require less cognitive capacity if better schemata are acquired or if more rules are automated. The findings concerning the cognitive-load variable, indexed by the perceived amount of mental effort, indicate that subjective measures of mental effort can be valuable research tools for assessment of cognitive load in instructional research. However, more research on this topic is needed.

Table 2
Mean Test Score as a Function of Condition

Problem type	Condition		
	Conventional	Worked	Completion
Near transfer	9.3	11.1	10.1
Far transfer	3.1	7.7	6.0

Note. Scores could range from 0 to 12.

Table 3
Mean Amount of Perceived Mental Effort as a Function of Condition

Task	Condition		
	Conventional	Worked	Completion
Specific instruction	2.6	2.4	2.3
OP_1	2.2	2.1	2.1
OP_2	3.5	4.6	3.8
OP_3	1.6	1.9	1.9
OP_4	3.3	3.7	2.5
Test	4.9	3.8	3.1
Near-transfer problems	4.4	3.4	2.7
Far-transfer problems	5.6	4.1	3.6

Note. OP = conventional problem. Subscripts represent problem numbers.

The results on transfer are similar to those found by Sweller (1988), Van Merriënboer (1990); and Van Merriënboer and De Croock (in press). Better transfer performance in the worked and completion conditions might be attributed to superior schema acquisition as a result of the type of training. Although mental effort during instruction did not differ in this study, one should note that the level of mental effort during instruction is not invariably associated with the quality of transfer performance. Whether differences in mental effort during instruction result in differences in transfer performance depends on the relevance of the processes required to work with the instruction. From the data on the initially generated incorrect solutions, it can be argued that the obstacle to schema acquisition in the conventional condition resulted from investing effort in learning erroneous procedures and generating erroneous solutions. As a result of limited cognitive capacity, less effort could be invested in more relevant processes, such as abstracting appropriate schemata.

An alternative explanation of the results is that the initial learning of erroneous procedures, and the initial construction of incorrect solutions in the conventional condition, interfered with the organization and hence the accessibility of knowledge in memory (Bassok & Holyoak, 1989). By directing attention to the goal-relevant aspects of the task and by providing concrete schemata, worked-out or partly worked-out problems might have prevented students from these capacity-demanding and organization-interfering activities. Because the quality of acquired schemata was not directly measured, this schema-based interpretation needs experimental confirmation. Future research, therefore, should attempt to determine the schemata acquired by students and the types of errors made by students (e.g., by using verbal reports as data and by compelling students to write down the solution steps).

A second alternative explanation of the results is that the superiority of the worked and completion strategies might have resulted from the sequence in which the subjects proceeded through study cycles (worked-out problems) and test cycles (conventional problems). After studying or completing two completely or partly worked-out problem solutions, the students in the worked and completion conditions also had to solve a conventional problem. It is possible that this direct opportunity to apply the acquired schemata caused the superior transfer results in these conditions. Future research should investigate this claim by taking into account a pure worked-out instruction.

The results of the experiment indicate an interrelationship between practice-problem type, mental effort, and transfer. In domains in which time and cognitive capacity are limiting factors, the allocation of instructional time for training for transfer should be changed in favor of worked-out problems. Such instruction can direct attention to goal-relevant task aspects, thus preventing students from generating incorrect solutions. Consequently, there is no waste of cognitive resources, and the organization of knowledge in memory is fostered.

Moreover, the reduction in time needed for training indicates that emphasizing worked-out problems in instruction provides the opportunity to increase the quality (e.g., variability) of practice, the quantity of practice, or both and consequently to facilitate schema acquisition and rule automation.

In formulating instructional prescriptions from the present research, one should take into consideration recent findings by Chi, Bassok, Lewis, Reimann, and Glaser (1989), who concluded from students' self-explanations that students' ability level determines the way in which they make use of worked-out examples. During problem solving, good students use the examples for a specific reference, whereas poor students reread them to search for a solution. Furthermore, good students seem to refer to the examples less frequently within each solution attempt. In light of these recent findings, the results of the present study legitimize the conclusion that instruction with emphasis on either worked-out problems or partly worked-out problems is an appropriate alternative to conventional instruction. At the same time, wholesale advocacy of worked-example instruction seems premature.

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