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Instructional Compensation for Age-Related Cognitive Declines: Effects of Goal Specificity in Maze Learning

Fred Paas
Open University of the Netherlands

Gino Camp and Remy Rikers
Maastricht University

The differential effects of goal specificity on maze learning among 40 young adults and 40 old adults were investigated. Participants had to navigate through a computerized training-maze task. The finish point of the maze could be presented either as a specific location or in more general terms. After solving the maze problem, participants were required to solve the same problem again, either by moving from start to finish or backward from finish to start. The hypotheses that the presence or absence of a specific goal would disproportionately compromise or enhance, respectively, elderly people's performance were confirmed. Although young adults outperformed old participants in all conditions, these differences were much smaller in the nonspecific goal conditions. These results suggest that instruction based on cognitive load theory (J. Sweller, J.J.G. Van Merriënboer, & F. Paas, 1998) can compensate for age-related cognitive declines.

Sweller and his colleagues (e.g., Bobis, Sweller, & Cooper, 1994; Owen & Sweller, 1985; Sweller & Levine, 1982) have provided evidence that the extent to which a goal is clearly specified to a problem solver as a problem state affects the problem-solving strategy used. In their experiments, Sweller and Levine (1982) used maze-tracing and numerical problems in which the finish point could be presented either as a specific location or in more general terms. These transformation problems are characterized by an initial problem state, a goal state, and a set of operators to transform the initial state into the goal state. The major mechanism used by problem solvers faced with transformation problems is means–ends analysis. The use of means–ends analysis and learning, that is, the construction of a cognitive schema of the underlying spatial structure of the maze, were independent. Under goal-specific conditions that facilitated the use of means–ends analysis, knowledge of the goal location was the primary factor controlling problem solvers' moves. This rendered the problem insoluble, and problem solvers were prevented from abstracting from the solutions the general rules used in problem solving. The nonspecific goal prevented the use of conventional means–ends analysis and resulted in fewer errors and more rapid learning of the structure of the problem. Sweller and Levine argued that in the absence of a goal, other aspects of the problem structure control moves. Under nonspecific goal conditions, the location of choice points and dead ends have increased influence, as they no longer compete with the goal of control, and problem solvers attempt to use information obtained from previous episodes to generate hypotheses concerning subsequent moves. This strategy, in which feedback from dead ends and choice points may be the predominant controlling mechanism, is termed a history-cued strategy.

Since the Sweller and Levine (1982) study, evidence for the effectiveness of goal-free problems has become strong, with the effect obtained under a wide variety of conditions and domains such as kinematics (Sweller, 1988), geometry (Bobis et al., 1994), mathematics (Mawer & Sweller, 1982), and biology (Vollmeyer, Burns, & Holyoak, 1996). Similar studies with other problem formats preventing the use of means–ends analysis, such as worked-out problems and completion problems, led to the same conclusions and, around 1988, evolved into the formulation of cognitive load theory (Sweller, 1988; for reviews, see Paas & Van Merriënboer, 1994a; Sweller, Van Merriënboer, & Paas, 1998).

Cognitive Load Theory

Cognitive load theory (CLT) is concerned with the development of instructional methods that efficiently use people's limited cognitive processing capacity to stimulate the ability to apply acquired knowledge and skills to new situations (i.e., transfer). CLT is based on a cognitive architecture that consists of a limited working memory (WM), with partly independent processing units for visual and auditive information, that interacts with an unlimited long-term memory. According to CLT, the limitations of WM can be circumvented by chunking multiple elements of information as one element in cognitive schemata, by automizing rules that can bypass WM during processing, and by using both visual and auditory WM processing units. Work within a cognitive load framework has concentrated on the efficient use of WM capacity by reducing extraneous cognitive load and by preventing the need to mentally integrate different sources of information.

Fred Paas, Educational Technology Expertise Center, Open University of the Netherlands, Heerlen, the Netherlands; Gino Camp and Remy Rikers, Department of Psychology, Maastricht University, Maastricht, the Netherlands.

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Correspondence concerning this article should be addressed to Fred Paas, Educational Technology Expertise Center, Open University of the Netherlands, P.O. Box 2960, 6401 DL Heerlen, the Netherlands. Electronic mail may be sent to fred.paas@ou.nl.

The superior results of CLT-based instructional formats have been obtained with children and young adults in a wide variety of domains such as physics (Ward & Sweller, 1990), mathematics (Tarmizi & Sweller, 1988), statistics (Paas, 1992), computer programming (Chandler & Sweller, 1992; Paas & Van Merriënboer, 1994b), geography (Purnell, Solman, & Sweller, 1991), biology and electrical engineering (Chandler & Sweller, 1991), paper folding (Bobis, Sweller, & Cooper, 1994), understanding empirical reports (Chandler & Sweller, 1992), and learning to use a computer program (Sweller & Chandler, 1994). Compared with conventional instructional tasks, CLT-based tasks were found to be more efficient in such a way that they lead to better learning and transfer performance with less training time and less mental effort.

None of the studies mentioned earlier included a group of older adults as participants. This is surprising given the findings of recent cognitive aging research, which suggest that this group may benefit, even more than younger adults, from instructional tasks in which the properties of the cognitive system are taken into account. In fact, there is a good match of the goals of CLT with the results of cognitive aging research (see also Van Gerven, Paas, Van Merriënboer, & Schmidt, 2000).

Cognitive Aging

One of the central findings in cognitive aging research is that the efficiency of WM operations declines with age in adults. A major focus of recent cognitive aging research has been on various explanations proposed to account for this decline. The most popular explanations are based on reduced WM capacity, slowed processing speed, difficulties inhibiting selected-against or irrelevant information, and deficits in integrative or coordinative aspects of WM.

The reduced WM capacity view suggests that an age-related loss of available capacity impairs the ability to engage in demanding operations. Indeed, there is a growing body of evidence that supports the hypothesis that age-related declines in cognitive performance are most likely to occur in complex cognitive tasks requiring effortful processing (e.g., Gilinski & Judd, 1994; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Wingfield, Stine, Lahar, & Aberdeen, 1988). Because these tasks are highly dependent on the availability of sufficient cognitive resources for their successful completion, they are disproportionately compromised by age-related declines in cognitive capacity. In particular, when tasks become more complex or require large amounts of mental processing, older adults appear to be slower than younger adults. With regard to the slowed processing speed view, variations in speed have often been argued to be at the center of observed age differences in performance (Fisk & Warr, 1996; Salthouse, 1994).

According to several recent theories that propose an active suppression or inhibition process that operates directly on unselected or distracting information, efficient selection is obtained not only by enhancing availability of selected information, but also by suppressing responses to irrelevant information (e.g., Hartman & Hasher, 1991; Stolzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993; Zacks & Hasher, 1997). Older people, however, cannot inhibit selected-against or irrelevant information to the same extent as do younger adults (Adam et al., 1998; Spieler, Balota, & Faust, 1996; Stolzfus et al., 1993). Consequently, according to this reduced inhibition view, irrelevant or extraneous information imposes more load on the cognitive system of older adults than that of younger adults.

The reduced integration or coordination view has received empirical support from various studies. With regard to deductive reasoning, Light, Zelinski, and Moore (1982) found that older adults were not able to integrate information across several premises, even when these premises could be accurately recognized. Much of the macrospatial research comparing memory for routes of young and old adults has found that memory for both novel and familiar environments decreases with age (e.g., Kirasic, Allen, & Haggerty, 1992; Lipman & Caplan, 1992). Older individuals' memory of landmarks is relatively unimpaired, but older individuals have difficulty with more integrative aspects involved in layout memory (Lipman & Caplan, 1992). Mayr and his collaborators (Mayr & Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996) used figural transformation tasks to show that age-related slowing is larger in coordinative complexity conditions than in sequential complexity conditions.

CLT × Cognitive Aging

The combination of the goals of CLT (i.e., efficiently use WM capacity by reducing extraneous cognitive load and by preventing the need to mentally integrate different sources of information) and the current perspectives on the nature of cognitive impairments in older adults (i.e., reduced WM capacity, slowed processing speed, difficulties inhibiting irrelevant information, and deficits in integrative WM) quite naturally led us to two hypotheses. First, older adults' performance can be expected to be disproportionately compromised by conventional practice with goal-specific problems, which impose a high extraneous cognitive load. Second, CLT-based instructive tasks such as goal-free problems may compensate for the age-related cognitive deteriorations and decrease the performance differences between young and old people. These hypotheses were tested in the present study with an adapted version of Sweller and Levine's (1982) maze-tracing task.

With the goal-specific maze, the attentional switching process from the subgoal states that are relevant for the underlying spatial rules or relationships to the irrelevant goal state is cognitive capacity demanding and interferes with schema construction. Because the integration of information and the suppression of irrelevant information are especially problematic for older people, we expected that this goal-specific maze would show large differences in learning and transfer performance between young and older participants. In contrast, we predicted that in the goal-free maze the differences in learning and transfer performance between younger and older participants would decrease. Goal-free problems prevent participants from paying attention to the irrelevant goal and might be expected to be particularly helpful for older adults, who have difficulty constructing coordinated networks of spatial relations.

The present study was designed to investigate the differential effects of goal specificity on maze learning and transfer of both younger and older adults. As such, this study can be considered a first step in identifying instructional procedures that can compensate for the age-related declines in WM, so that older adults may be able to perform at levels comparable with younger adults.

Method

Participants

Forty young university students (mean age = 20.2 years, *SD* = 3.6 years) and 40 old adults (mean age = 72.4 years, *SD* = 8.9 years) participated in this study. There were 20 women and 20 men in each age group. The elderly participants were selected from a participant pool provided by the Maastricht Aging Study (Jolles, Houx, Van Boxtel, & Ponds, 1995). All participants were in good health and had normal or corrected-to-normal vision. They received 10 Dutch guilders (about $5) per hour and were offered reimbursement of their travel expenses.

On a short form of the Groningen Intelligence Test (GIT; Luteijn & Van der Ploeg, 1983), estimates of IQs did not differ as a function of age (young: $M = 123.9$, $SD = 10.4$; old: $M = 120.8$, $SD = 13.0$), $t(78) = 1.24$, *ns*). The GIT is the commonly used Dutch estimate of formal IQ. Four subtasks of the test were administered to arrive at a reliable estimation of IQ. There is general agreement on which subtasks have to be used to arrive at the best possible approximation of a full-scale IQ: Doing Sums, Vocabulary, Mental Rotation, and Analogies.

Materials

An adapted version of Sweller and Levine's (1982) maze-tracing task was used in the present study. An IBM-compatible computer (P-166) was used for stimulus presentation and response collection. The software controlling the experiment was programmed in Delphi 3.0. The maze task was displayed on a 17-in. SVGA Phillips color monitor (800 × 600 pixels) with an integrated AccuTouch touch-screen (ELO TouchSystems, Fremont, CA). The experiment took place in a normally lit room that contained the touch-screen-equipped computer. Participants sat in front of the monitor and interacted with the computer by touching the screen with the index finger of their preferred hand. Viewing distance for participants was approximately 50 cm. The monitor was always illuminated with a dark blue background color. The maze elements had a light gray color. All elements of the maze were approximately 1.5 cm^2. At the start of the task, participants in the goals-specific condition saw a square (side length = 1.5 cm) that contained the word START and the goal square of the same size containing the word FINISH. The search space was a rectangular area, approximately 26 × 20 cm, on the surface of the monitor.

Familiarization. Familiarization with the experimental maze-tracing task consisted of a short condition-specific maze task. Participants in the goal-specific and goal-free forward conditions had to navigate two times from start to the finish, whereas participants in the backward conditions first navigated from start to finish and then had to return via the same route, from finish to start. The goal-specific conditions differed from the goal-free conditions with regard to the visibility of the goal state. That is, in the goal-specific condition, the finish was visible, and in the goal-free condition, it was not. The minimum number of steps required to reach the finish was 6.

Training and test. Figure 1 shows the problem space of the test-maze task. The minimum number of steps required to reach the finish of the training and test maze was 12.

Transfer. The route reversal task in the present maze was considered a transfer task. Of course, it is known intuitively that returning to the origin by the same paths that were used to reach the destination differs from going from the origin to the destination. Consistent with this intuition, process analysis by Brown (1976) has shown that backward reconstruction of a route is cognitively more demanding than forward reconstruction.

Design and Procedure

Participants were randomly assigned to one of the four experimental conditions (i.e., young, goal specific; young, goal free; old, goal specific; and old, goal free), with the restriction that each condition contained 10 men and 10 women. The participants were tested individually.

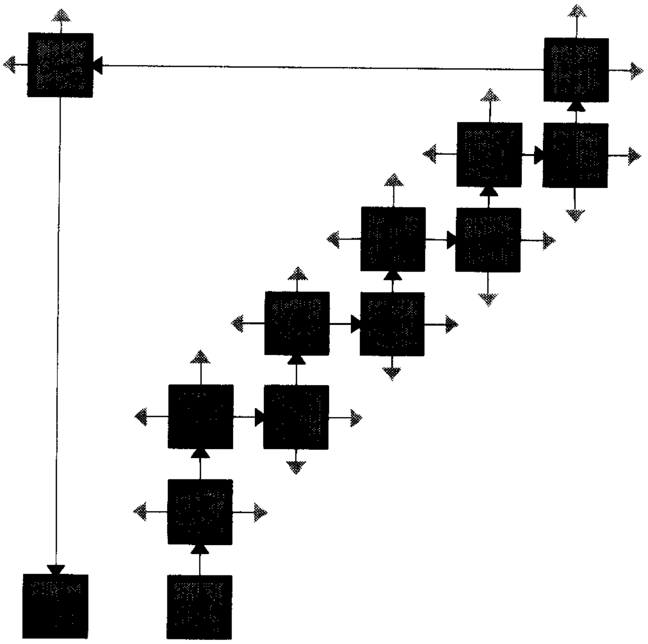

Figure 1. Problem space of the maze-tracing task. Black arrows represent correct choices and the ideal route from start to finish. Gray arrows represent incorrect choices.

At the beginning of the experiment, participants were informed about the goal of the experimental task: to find the shortest way, within the shortest time, through a maze from the start to a visible goal area (i.e., goal-specific condition) or an invisible goal area (i.e., goal-free condition). For familiarization purposes, the participants were then presented with a similar condition-specific but short practice-maze task. During familiarization, participants in the goal-specific forward condition had to navigate two times from start to finish, whereas participants in the goal-specific backward condition first navigated from start to finish and then had to return via the same route, from finish to start. Furthermore, in the goal-specific conditions, the goal was visible, and in the goal-free conditions, it was not. After obtaining confirmation that the participant had understood the task and the interface, the experimenter started the training program. Registration of time and responses started when the participant touched the START square on the computer screen. After practice, participants were confronted with a condition-specific test maze. The structure of the maze was the same in all conditions, but analogous to the practice maze, goal specificity and test direction varied across conditions. A cluster of squares appeared at every choice point. Participants were able to choose from four alternatives (up, down, left, and right) by pushing the corresponding square on the screen. If an icon of a closed door appeared on the chosen square, participants knew that they had attained a dead end and had to return to their previous choice point. When the correct alternative was chosen, as indicated by an icon of an open door appearing in the chosen square, the corresponding square became the next choice point, surrounded by four new alternatives, one of which was the previous choice point. At any point in time, only the start position and the current choice point were displayed on the screen, thereby masking the previous steps and the spatial properties of the maze. In the goal-specific conditions, the finish position was also permanently displayed. The training session ended after the participant attained the goal. Then, with the identical maze pattern, the test task was to locate the same goal by going forward from the start to the finish (i.e., learning) or proceeding backward from the finish to the start (i.e., transfer). In both conditions, the experimenter emphasized that participants should use the least number of steps and the shortest time possible.

Time and number of steps needed for completing the maze task were measured. Solving the maze for the second time was considered a transfer task in the backward condition, whereas in the forward condition, it was considered a learning task. Thus, in the forward conditions, the participants performed the same task twice, whereas in the backward conditions, participants were required to do a related but different task.

Results

Training-Maze Data

The training-maze data were analyzed with 2 (Age: young vs. old) × 2 (Goal Specificity: goal specific vs. goal free) analyses of variance (ANOVAs), with Age and Goal Specificity as between-subject factors. Number of steps and time to reach the finish were used as dependent variables. Table 1 shows the means and standard deviations for the number of steps and the time (in seconds) needed to reach the finish of the training maze as a function of age and goal specificity.

An ANOVA on the mean time needed to reach the goal state of the training maze yielded main effects of age, $F(1, 76) = 47.42$, $p < .0001$, $MSE = 3279.46$, and goal specificity, $F(1, 76) = 47.36$, $p < .0001$, and a significant Age × Goal Specificity interaction, $F(1, 76) = 17.02$, $p < .0001$. Younger adults were faster than older adults, and both younger and older adults completed the maze task significantly faster in the goal-free condition than in the goal-specific condition. The interaction effect of Age × Goal Specificity suggests that age differences were larger in the goal-specific condition compared with the goal-free condition (see Table 1). This was confirmed with additional interaction contrasts for goal-free and goal-specific conditions. For goal-specific conditions, contrast analyses yielded meaningful differences between young and old conditions ($M = 141.0$ s), $F(1, 38) = 60.62$, $p < .0001$. Under goal-free conditions, the differences between young and old adults were much smaller ($M = 35.3$ s), $F(1, 38) = 3.81$, $p = .055$. Consistent with our hypotheses, older adults needed proportionately more time than young adults in the goal-specific conditions and could gain proportionately more from the goal-free conditions.

There were main effects of age, $F(1, 76) = 9.82$, $p < .005$, $MSE = 883.12$, and goal specificity, $F(1, 76) = 26.68$, $p < .0001$, with respect to the number of steps needed to reach the goal state. The young adults outperformed the old adults, and the finish in the goal-free condition was attained with fewer moves than in the goal-specific condition. The Age x Goal Specificity interaction approached significance, $F(1, 76) = 3.06$, $p = .084$; the older adults profited more from the goal-free condition than did the young adults. Because this interaction was of a priori interest, contrast analyses on each of the goal-specificity groupings were performed. For the goal-specific conditions, the contrast revealed a reliable difference between young and older adults, $F(1, 38) = 11.92$, $p < .001$. Older adults needed an average of 32.5 more steps than the young adults. In the goal-free conditions, there was no difference between the age groups, $F(1, 38) = 0.96$, *ns*.

Test-Maze Data

Mean number of steps and mean time to reach the finish were analyzed with 2 (Age: young vs. old) × 2 (Goal Specificity: goal specific vs. goal free) × 2 (Maze Direction: forward vs. backward) ANOVAs, with Age, Goal Specificity, and Maze Direction as between-subject factors. The means and standard deviations for the number of steps and the time (in seconds) needed for reaching the finish of the test maze at each level of goal specificity for both age groups (collapsed across maze direction) are shown in Table 1.

The ANOVA performed on the mean time needed to reach the goal state of the test maze yielded main effects of age, $F(1, 72) = 29.64$, $p < .0001$, $MSE = 1363.33$, and goal specificity, $F(1, 72) = 7.53$, $p < .01$. Younger adults were faster than older adults, and both younger and older adults completed the maze task significantly faster in the goal-free condition than in the goal-specific condition. The main effect of test-maze direction was not significant, $F(1, 72) = 0.92$, *ns*. There was a significant Age × Goal Specificity interaction, $F(1, 72) = 5.61$, $p < .05$; age differences were larger in the goal-specific conditions ($M = 64.5$ s) than in the goal-free conditions ($M = 25.4$ s). Contrast analyses for each goal-specificity grouping confirmed the significant differences between young and older adults for the goal-specific condition, $F(1, 38) = 31.08$, $p < .0001$, and for the goal-free condition, $F(1, 38) = 4.82$, $p < .05$. The two-way Age Group × Test-Maze

Table 1
Time and Number of Steps Needed to Complete the Training and Test Mazes as a Function of Experimental Condition

	Experimental condition							
	Young				Old			
	Goal specific		Goal free		Goal specific		Goal free	
Dependent variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Time (in seconds)								
Training maze	84.3	44.9	49.1	15.9	225.3	99.3	84.4	31.3
Test maze	25.8	8.3	22.7	7.4	90.3	69.1	48.1	20.5
Number of steps								
Training maze	63.6	31.5	40.9	6.5	96.1	47.6	50.1	15.1
Test maze	28.1	5.0	27.0	3.4	47.6	25.8	37.0	8.8

Direction interaction, $F(1, 72) = 0.40$, *ns*, and Goal Specificity × Test-Maze Direction interaction, $F(1, 72) = 0.41$, *ns*, and the three-way Age Group × Test Direction × Goal Specificity interaction, $F(1, 72) = 0.90$, *ns*, were not significant.

With regard to the test maze, there was a main effect of age, $F(1, 72) = 21.16, p < .0001, MSE = 199.43$, with respect to the mean number of steps needed to reach the goal state of the maze, such that the young adults outperformed the old adults. The effect of goal specificity approached significance, $F(1, 72) = 3.76, p = .056$. The finish in the goal-free condition was attained with fewer moves than in the goal-specific condition. The effect of test-maze direction was not significant, $F(1, 72) = 0.02$, *ns*. The Age × Goal Specificity interaction approached significance, $F(1, 76) = 3.06, p = .084$, with the older adults profiting slightly more from the goal-free condition than the young adults. Contrast analyses on each of the goal-specificity groupings revealed that in the goal-specific conditions, older adults needed an average of 19.5 more steps than the young adults, $F(1, 38) = 19.36, p < .0001$. In the goal-free conditions, the older adults needed only 10.0 more steps than the young adults, $F(1, 38) = 4.57, p < .05$. None of the other two- and three-way interactions was significant: Age Group × Test-Maze Direction, $F(1, 72) = 0.20$, *ns*; Age × Goal Specificity, $F(1, 72) = 2.53$, *ns*; Goal Specificity × Test-Maze Direction, $F(1, 72) = 1.35$, *ns*; Age Group × Test Direction × Goal Specificity, $F(1, 72) = 1.67$, *ns*.

Discussion

On the basis of the combination of the goals of CLT and the current perspectives on cognitive aging, we hypothesized that the presence or absence of a specific goal would disproportionately compromise or enhance, respectively, elderly people's learning and transfer performance. Indeed, the young adults outperformed old participants in most conditions. Consistent with CLT, the goal-free format of the maze produced better learning performance for both young and old adults. As predicted, we found an interaction between age group and goal specificity. First, large differences were found between young and old adults in the goal-specific conditions in time and number of steps on both the training maze and the test maze, indexing much poorer learning and transfer for the older adults. These differences were smaller, however, when a goal-free format was used. The use of goal-free problems narrowed the gap between WM performance of young adults and that of older adults by compensating for the age-related cognitive declines. Goal-free problems prevent the use of means–ends analysis, thereby saving cognitive resources that can be used for processes relevant for learning. This is especially useful for elderly people, who can partially compensate for their WM limitations. With regard to lifelong learning in those areas where problem-solving performance is critical, such as mathematics and physics, an emphasis on goal-free problems can be effective. In contrast to conventionally used goal-specific problems, goal-free problems prevent learners from using a means–ends search. A means–ends search places heavy demands on limited WM, and these demands are largely irrelevant for learning. With instructional formats that compensate for the age-related cognitive declines, older adults seem to be able to attain performance levels comparable to those of young adults.

The hypothesis that transfer performance in the form of backward reconstruction of the maze task would lead to the largest differences in performance as a function of goal specificity was not confirmed. In contrast to Brown (1976), backward reconstruction of the spatial structure of the present maze task seems to be just as demanding as forward construction. A possible explanation for this is that there was not enough practice with the maze to enable the participants to do a transfer task such as the one required in the backward condition. If there is not enough practice available for both groups to successfully do the backward (transfer) task, then no beneficial effects of the goal-free format should be expected, as both groups should perform equally poorly. Future research that provides more practice before a transfer task is necessary to determine whether goal-free problems lead to better transfer.

Another noteworthy finding of this study is that interaction effects between the age and goal-specificity factors were found only with regard to the dependent variable of time to solve the maze task. This might be a characteristic feature of the present task, but it also suggests that goal specificity of practice problems has effects on speed performance without sacrificing accuracy. This finding is also consistent with the slowed processing speed view on cognitive aging, which argues that the general slowdown at which information is activated within the WM is at the center of observed age differences (e.g., Fisk & Warr, 1996).

Within the context of CLT, the results of the present study have strong implications for the design of instructional procedures that can compensate for the age-related cognitive declines. We believe that the present results, in combination with the results of previous studies in the context of CLT, are promising in terms of lifelong learning. Of course, the results need further experimental confirmation with other CLT-based instructional formats (e.g., worked examples and completion examples), in other more realistic complex domains, and under different experimental task conditions. With regard to the task conditions used in the present study, it should be noted that the participants were instructed to find the correct solution with the least steps and in the shortest time. Future research should study the effects of other configurations of task conditions. Van Gerven, Paas, Van Merriënboer, and Schmidt's (in press) recent study can be considered a first successful attempt to test another instructional format in another domain. Within the domain of Luchins's (1942) water jug problem, they investigated the instructional efficiency of studying worked examples and solving conventional problems as a function of age. The results were in line with the results of the present study, showing that the older participants in the worked-examples condition needed less time and mental effort than did those in the conventional-problems condition to attain the same performance level. Although we believe that these effects will also be found for other domains using transformation problems, such as mathematics, biology, and kinematics, we can only speculate about the relevance of the present maze task to real-world, every day cognition tasks. Research in that area has begun.

In summary, the results of this study contribute to the identification of instructional strategies that can compensate for the age-related declines of cognitive capacity, integrative aspects of WM, and the ability to suppress responses to irrelevant information. Future research in the context of lifelong learning would profit from a focus on the identification of instructional strategies for compensating age-related cognitive declines.

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