Educational Gerontology, 26: 503–521, 2000

0360-1277/00 $12.00 +.00

COGNITIVE LOAD THEORY AND THE ACQUISITION OF COMPLEX COGNITIVE SKILLS IN THE ELDERLY: TOWARDS AN INTEGRATIVE FRAMEWORK

Pascal W. M. Van Gerven
Department of Psychology, Maastricht University, Maastricht, The Netherlands

Fred G. W. C. Paas
Jeroen J. G. Van Merriënboer
Educational Technology Expertise Center (OTEC), Open University of The Netherlands, Heerlen, The Netherlands

Henk G. Schmidt
Department of Psychology, Maastricht University, Maastricht, The Netherlands

The purpose of this article is to explore the advantages of instructional formats based on cognitive load theory for elderly learners engaged in the acquisition of complex cognitive skills. A great body of research has demonstrated that cognitive aging is accompanied by a reduction of working-memory capacity, a general slowing of mental processes, and a decline of the ability to repress irrelevant information. The core idea of cognitive load theory is that working-memory capacity is limited and should therefore be managed with great care and discretion. Cognitive load theory claims that this can be achieved by minimizing the level of extraneous cognitive load, which is the portion of load that does not contribute to schema acquisition, and by maximizing the level of germane cognitive load, which directly

The authors wish to thank John Sweller and Paul Chandler (University of New South Wales, Australia) for their very helpful comments on a draft of this article.

The Netherlands Organization for Scientific Research (NWO) is gratefully acknowledged for funding this project.

Address correspondence to Pascal van Gerven, Department of Psychology, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands. E-mail: p.vangerven@psychology.unimaas.nl

contributes to the construction of cognitive schemata. Since instructions based on cognitive load theory deal with cognitive limitations, in that they lead to an efficient use of the available resources, it was hypothesized that they are especially effective when elderly people are involved. This idea was analyzed by means of a framework merging cognitive load theory with the aforementioned research findings concerning cognitive aging. It was concluded that cognitive load theory, enabling elderly people to acquire new complex skills, can be regarded as an essential guide for educational gerontology.

It has become a platitude to proclaim that our society is developing at an incredible speed, that its complexity is becoming enormous, and that we are daily overloaded with information. In the same light, it has become a truism that old people are more affected by this immensity than young people. Where, in the worst case, young people seem to be suffering from growing information quantity and complexity, old people are likely to be totally overwhelmed by it. Not surprisingly, a frequently uttered complaint of elderly people being confronted with, for instance, computer-based work (Morris, 1994), is that they are overburdened with numerous options, inadequately presented information, and jargon, which not only leads to poor performance, but also leaves them with a negative attitude towards the subject matter. Fortunately, this observation is broadly recognized as a problem, not least because the elderly represent a relatively large and still growing part of advanced industrial populations.

Cognitive overload frequently plays a role in education. Research into some aspects of cognitive processing and instructional design has provided solutions to this problem. Much of this research seizes upon the issue of what can be done to manage cognitive load in such a way that people achieve optimal learning and performance. In this article we present a framework that integrates research findings in the field of cognitive load and cognitive aging. This framework is based on the assumption that using knowledge of factors determining cognitive load can lead to more effective instructions, and thus to enhanced performance of the learner. One of the theories that focuses on cognitive load and provides important guidelines for improving instructional material is Sweller's (1988, 1989, 1994) cognitive load theory (CLT). The question raised in this article is whether CLT-based modifications of conventional instructional material, having been extensively tested on relatively young subjects, are also effective with elderly people in a problem-solving context. In fact, we claim that the assertions of CLT perfectly match the cognitive declines associated with aging. Therefore, we hypothesize that elderly people gain relatively more from CLT-based instructions than do young people (Van Gerven, Paas, & Van Merriënboer, 1998). Such instructions should enable older people to acquire skills that are otherwise far too intricate for them to grasp. Regarding the growing interest in lifelong learning, this can have a great impact on educational gerontology.

In working towards a framework of cognitive load and cognitive aging, we first shed some more light on the concept of cognitive load, its causal factors, and its relation to learning. Subsequently, we discuss the cognitive changes that are associated with aging. Next, we give a brief description of cognitive load theory and its implications for instructional design. Guided by the above-mentioned framework, we finally explain the implications of cognitive load theory for elderly learners.

COGNITIVE LOAD AND LEARNING

A comprehensive overview of factors determining the level of cognitive load is offered by Paas and Van Merriënboer (1994a; Figure 1). They distinguish causal and assessment factors. *Causal factors* include characteristics of the subject (e.g., age and cognitive abilities), the task (e.g., task complexity and time pressure), the environment (e.g., noise and temperature), and their mutual relations.

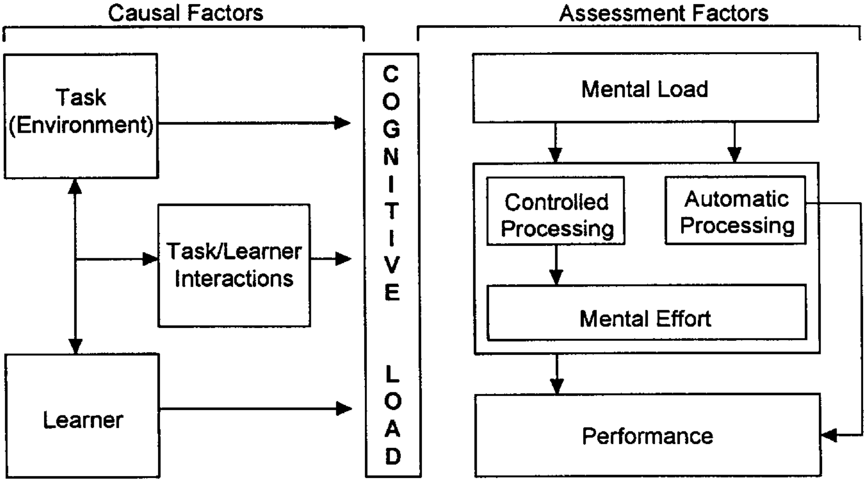

FIGURE 1 Cognitive load: causal and assessment factors (Paas & Van Merriënboer, 1994a).

With respect to *assessment factors*, Paas and Van Merriënboer distinguish mental load, mental effort, and performance as the three measurable dimensions of cognitive load. *Mental load* is regarded as the portion of cognitive load that is imposed exclusively by the task and environmental demands. The *mental-effort* dimension refers to the amount of cognitive capacity that is actually allocated to the fulfillment of the task. It pertains to the part of processing that is under mental control (as opposed to automatic processing). The subject's *performance*, finally, is a reflection of mental load, mental effort, and the aforementioned causal factors.

Learning, which is reflected by performance change, requires working-memory capacity. That is, it imposes a *germane cognitive load* on the learner (Sweller, Van Merriënboer, & Paas, 1998). Germane cognitive load is required for an essential aspect of learning, namely the construction and storage of so-called *schemata* into long-term memory. Schemata evolve when information elements and production rules are integrated and chunked into wholes. This process saves storage capacity and optimizes cognitive functioning. Sweller (1994, p. 296) defines a schema as a "cognitive construct that organizes the elements of information according to the manner with which they will be dealt." Following this definition, several types of schemata can be distinguished that relate to several types of situations. Schemata dealing with solving problems play a major role in this paper. According to Sweller (1994), a "problem-solving schema" is a flexible instrument that captures a problem into a specific category and provides the *rules* for solving it.

An important feature of schemata is that they enable *transfer*. Transfer is the application of existing schemata to new problems, which can be tackled similarly to related, earlier encountered problems. Transfer is essential for the performance of complex tasks, in which the encountered problems often deviate from the standard. Another essential feature of schemata is *automation*. Schemata that are automated do not require controlled processing anymore (see Figure 1). As a result, even more than the original schemata, automated schemata reduce mental effort and thus cognitive load (Van Merriënboer & Paas, 1990).

The construction of adequate and rich schemata is especially important in complex learning tasks. Complex learning tasks require more effort, because the elements contained by the to-be-learned material are highly interconnected (Sweller, 1994). In this respect, Sweller refers to *intrinsic cognitive load*, which is the portion of load that is imposed by the intrinsic characteristics of the task or subject matter. Tasks imposing a high intrinsic load often strain the cognitive system to its limits. In the next section, we will see that this is especially the case when the cognitive system has declined as a result of aging.

CHARACTERISTICS OF COGNITIVE AGING

Cognitive aging is accompanied by important cognitive changes. These concern both crystallized and fluid abilities (e.g., Horn & Cattell, 1967). Where crystallized abilities enhance and accumulate as a result of aging, fluid abilities tend to decline. This decline is threefold: (1) working-memory capacity decreases, (2) processing speed goes down, and (3) there is a reduced ability to distinguish relevant from irrelevant information. In the following subsections we will elaborate on these declines.

Reduced Working-Memory Capacity

Decrease of working-memory capacity seems to be the most obvious cognitive change associated with aging. The concept of *working memory* categorically differs from the somewhat obsolete expression, "short-term memory." That is, the term is not simply defined as the ability to temporarily store a certain number of information elements, but rather as the capacity "to preserve information while simultaneously processing the same or other information" (Salthouse & Babcock, 1991, p. 763). Whereas simple short-term storage capacity barely declines with aging, working memory does. Wingfield, Stine, Lahar, and Aberdeen (1988), for instance, found no difference between young and old subjects in a digit-span test and only a small difference in a word-span test. In a loaded word-span test, however, in which subjects had to make a false/true judgement about and recall the last words of progressively longer sets of statements, elderly subjects were substantially affected. Salthouse and Babcock (1991) obtained similar results. Where they found a relatively weak relation between age and digit/word-span, they found a gradual age-related decline in listening and computation span.

Reduced working-memory capacity becomes critical when the task demands are high and a relatively large working-memory capacity is needed. A considerable body of research illustrates the importance of working-memory capacity for problem-solving skill. A study by Gilinsky and Judd (1994), for instance, demonstrates the role of reduced working-memory capacity in solving syllogistic problems. The difficulty of solving syllogistic problems depends on the number of "solution models" that has to be evaluated in working memory. Elderly subjects were more affected than their young counterparts when this number was high. Similar relations between age and task complexity were found in dual-task performance (Lorsbach & Simpson, 1988), computer-based work (Czaja & Sharit, 1993), and prospective tasks (Kidder, Park, Hertzog, & Morrell, 1997; Einstein, Smith, McDaniel, & Shaw, 1997).

Reduced Processing Speed

A second cognitive change associated with aging is a reduction of processing speed. This can be considered as an additional decline, but it can also serve as an alternative explanation for the age-related reduction of working-memory capacity. Salthouse and Babcock (1991), for instance, explain the phenomenon as a decrease in the rate at which information is activated. The number of information elements that can be processed simultaneously equals the number of elements that can be activated before the activation of the first element has decayed below a threshold. Hence, the lower the activation speed, the less elements can be processed. This view was the precursor of Salthouse's (1996) *processing-speed theory*. In this theory, Salthouse postulates two mechanisms underlying an age-related decline of cognitive performance. First, there is the limited-time mechanism, which is based on the assumption that the time occupied by early processes puts restrictions on the time available for later processes. Second, Salthouse posits the simultaneity mechanism, holding that products of early processes can be lost by the time later processes are executed. That is, products of different processing stages, which have to be combined at another stage of processing, are not always available simultaneously. Most importantly, Salthouse hypothesizes that general cognitive slowing, rather than a specific deficit, such as a reduced working-memory capacity, underlies age-related declines of cognitive functioning. The general nature of cognitive slowing implies that there are high correlations between different speed measures. Thus, a measure of perceptual speed, for instance, should be a reliable predictor of motor speed and vice versa. Furthermore, speed measures should highly correlate with measures of working memory. Finally, the theory predicts that statistical control of cognitive speed will attenuate an age-related difference of working-memory capacity. Such an attenuation was found repeatedly (e.g., Salthouse & Babcock, 1991; Salthouse, 1993; Fisk & Warr, 1996).

Myerson, Hale, Wagstaff, Poon, and Smith (1990) proposed a model that is consistent with Salthouse's simultaneity mechanism. In their *information-loss model*, they state that information processing occurs in discrete steps and that a person's response latency equals the sum of the step latencies. The duration of a step depends on the amount of information that is available at the onset of that step (cf. Salthouse, 1996). Unlike processing-speed theory, the information-loss model explicitly incorporates task complexity. That is, the more complex the task, the more processing steps are supposed to be involved (though Myerson et al. admit that this is an oversimplification). More processing steps will lead to proportionally more information loss and thus to lower performance. The number of processing steps required for a particular task does not depend on age. What increases with age is the duration per step as well as the proportion of information loss per step. As a consequence, elderly learners display a larger performance slide (i.e., longer latencies and a lower decision accuracy) than younger people when confronted with complex tasks.

Reduced Ability to Distinguish Relevant from Irrelevant Information

A third cognitive change emerging from old age is a decline of the ability to discriminate between relevant and irrelevant information. This phenomenon is generally ascribed to increased neural noise (e.g., Welford, 1985). This view is supported by studies showing that elderly subjects are poor performers on visual search tasks in which targets are surrounded by non-target objects (Allen, 1990; Allen, Madden, Groth, & Crozier, 1992; Madden, Connelly, & Pierce, 1994).

A view that is in line with the neural-noise approach is the idea of reduced inhibition (Hasher & Zacks, 1988; Hartman & Hasher, 1991). In this view, elderly people are assumed to have difficulty inhibiting irrelevant information in favor of relevant information. Again, this approach can be seen as an alternative for the reduced-capacity view. That is, the problem may not be that the potential of working memory has decreased, but rather that working memory tends to get overloaded with irrelevant information.

COGNITIVE LOAD THEORY AND INSTRUCTIONAL DESIGN

The above studies are all concerned with task performance. We are interested in a special task, namely the processing of instructions, which should lead to the acquisition of new and complex problem-solving skills that require transfer. The extent to which new skills are learned is determined by the effectiveness of the instructions. In the light of the aforementioned aging studies, this is particularly true when elderly learners are involved. Instructions aimed at elderly learners should be designed in such a way that their cognitive limitations are taken into account as much as possible. For this purpose, cognitive load theory (Sweller, 1988, 1989, 1994) provides some important guidelines. In *cognitive load theory* human memory is assumed to consist of a limited working memory connected to an unlimited long-term memory. It is further assumed that working memory is not a single entity, but that it embodies at least two mode-specific components: the *visuospatial sketch pad* and the *phonological loop*. Furthermore, it incorporates a coordinating component: the *central executive* (e.g., Baddeley, 1992). As we will see, this architecture can play a crucial role in managing cognitive load.

Basically, cognitive load theory is concerned with the limitations of working-memory capacity. Sweller and others (e.g., Paas, 1992; Paas & Van Merriënboer, 1994a, 1994b) state that, especially in conventional instructional design, the strict boundaries of working memory are rarely taken into account. Conventional instructions tends to impose an *extraneous cognitive load* on working memory and ignore the simple fact that to actually learn something from the instructions an additional germane cognitive load, and thus additional working-memory capacity, is indispensable. Thus, the limitation of working memory should impel instructional designers to develop training materials that impose a minimal extraneous load on working memory in order to reserve capacity for processes that have first priority, namely schema acquisition and automation. Therefore, a second important goal of instructions should be to stimulate the learner to actually dedicate the capacity gained to the schema-acquisition process.

The aim of conventional instructions is usually twofold. First, the learner is confronted with general information about the subject matter presented as text and, where applicable, as figures or diagrams. Second, a great deal of conventional instructions, especially those aimed at problem solving (e.g., in mathematics and physics), incorporate a practice session, the purpose of which is to improve performance and to provide feedback. According to Sweller and collaborators, it is exactly this practice session, which, at least in the initial phase of skill acquisition, is ineffective. Paradoxically, this ineffectiveness is especially evident when clear goals are specified. Goal-specific problems are usually solved by applying a so-called *means-ends strategy*. A means-ends strategy typically entails backward reasoning. That is, a goal state is set, which can be attained by solving all underlying subgoals in a backward order. This way, a student is constantly trying to find the means needed to attain a subgoal, while keeping in mind the higher goals in the hierarchy, including the main goal. The problem is that a means-ends strategy puts a relatively heavy burden on working memory, while not contributing to the construction of schemata (Sweller & Levine, 1982). The more complex the practice problems, the more working-memory capacity is demanded by a means-ends strategy, and the less capacity is available for schema acquisition. Apparently, practice does not make perfect in this context.

But what alternatives do we have? The answer to this question lies in the notion that instructions and training should be primarily aimed at the acquisition of cognitive schemata (Sweller, 1989). Once schemata are acquired and automation has taken place, problems are categorized and solved more rapidly and with less effort. Several CLT-based alternatives for conventional instructions have been proposed and evidence has been provided that these alternatives are superior. What CLT-based instructions have in common is that they restrict the amount of extraneous cognitive load to a minimum and at the same time, stimulate the learner to devote the available capacity to the construction of schemata. The most important CLT-based instructional formats are discussed in the following section (for an exhaustive overview see Sweller, Van Merriënboer, & Paas, 1998).

IMPORTANT CLT-BASED INSTRUCTIONAL FORMATS

Goal-Free Problems

Contrary to conventional goal-specific problems, goal-free problems do not allow learners to employ means-ends strategies (Sweller, 1989). The instruction "calculate the value of variable X," for instance, can be reformulated as "calculate the value of as many variables as you can." The specific goal is thus altered into a nonspecific goal. Instead of reasoning backward, the learner is now likely to reason forward, so that there is no need to keep the main goal and its subgoals in mind. This saves valuable working-memory capacity, which can be used for the construction of schemata. Moreover, goal-free reasoning leads to a more exhaustive exploration of the subject domain and, therefore, to the construction of extensive schemata which integrate more interconnected elements. Such schemata enable the solution of a broader range of problems and increase the probability of achieving transfer. Instruction formats containing goal-free problems have been proved to results in better performance than instructions containing goal-specific problems (Owen & Sweller, 1985; Sweller & Levine, 1982).

Worked Examples

Intuitively, practicing seems the ultimate means of getting insight into complex material. After all, by solving practice problems, the student is actively processing the subject matter. Moreover, the satisfaction of working towards and finding a solution can be an important motivational factor. Nevertheless, a number of studies have shown that a more effective alternative for problem solving is studying worked examples (Sweller & Cooper, 1985; Ward & Sweller, 1990; Paas, 1992; Paas & Van Merriënboer, 1994b). Unlike conventional practice problems, worked examples, being problems accompanied by their worked-out solutions, do not compel students to apply a capacity-demanding means-ends strategy. Instead, they can use their whole cognitive capacity to achieve a full comprehension of the subject matter.

Avoiding Split Attention

In general, instructions should be presented in such a way that the learner is not obliged to first convert them into a comprehensible form. One of the weaknesses of conventional instructions is that they often comprise mutually referring sources of information, which force learners to split their attention. An example is a diagram accompanied by a caption. Because, generally, neither of these two information sources can be understood on its own, they have to be mentally integrated. According to Sweller (1989), this integration process imposes a high extraneous load. Sweller argues that one of the means to reduce this unnecessary mental load is to physically merge the two information sources into a whole. The physical integration of interdependent information sources has been extensively tested against the traditional, nonintegrated format and found to be superior (Sweller, Chandler, Tierney, & Cooper, 1990; Chandler & Sweller, 1992; Bobis, Sweller, & Cooper, 1993; Sweller & Chandler, 1994).

Distributing Information over Different Modalities

As we have seen, cognitive load theory assumes that working memory comprises at least two independent, modal channels: a visuospatial sketch pad and a phonological loop (e.g., Baddeley, 1992). This view yields another tool for avoiding split attention. That is, if we assume that the visuospatial sketch pad and the phonological loop operate independently and in parallel, two sources of mutually referring information can be presented simultaneously via the visual and the auditory channels. In this dual-coding approach (e.g., Clark & Paivio, 1992), mental working-memory capacity is spared, so that more resources are available for schema acquisition. Dual coding was found to lead to better comprehension in different domains (Mousavi, Low, & Sweller, 1995; Tindall-Ford, Chandler, & Sweller, 1997; Mayer & Moreno, 1998; see Penney, 1989, for an extensive overview of modality effects).

Leaving Out Redundant Information

It is not always necessary to mentally integrate mutually referring information sources. In the case where two different sources of information can be understood on their own, one of them is often redundant. The usual assumption with respect to different instances of similar information in, for instance, computer manuals, is that in the worst case redundant information is simply ignored by the learner. It has been demonstrated, however, that discarding redundant information from instructional material has beneficial effects on comprehension and performance (Chandler & Sweller, 1991; Bobis et al., 1993).

TOWARDS AN INTEGRATIVE FRAMEWORK OF COGNITIVE LOAD THEORY AND COGNITIVE AGING

How can we now reformulate the above findings concerning cognitive aging and cognitive load theory into an explanatory and predictive framework? We propose a framework, which on the one hand incorporates and explains cognitive load theory, and on the other hand predicts the effects of CLT-based instructions under conditions of high task complexity and reduced cognitive abilities. A schematic representation of the framework is depicted in Figure 2. The left side of the figure contains three independent bipolar variables: instructions, age, and task complexity. These variables establish the basic task and learner characteristics. Instructions are either "conventional" or "CLT-based," age is either "young" or "old," and task complexity is either "low" or "high." The boxes in the figure contain dependent variables. The arrows represent causal relations. Minus signs indicate negative connections; plus signs indicate positive connections.

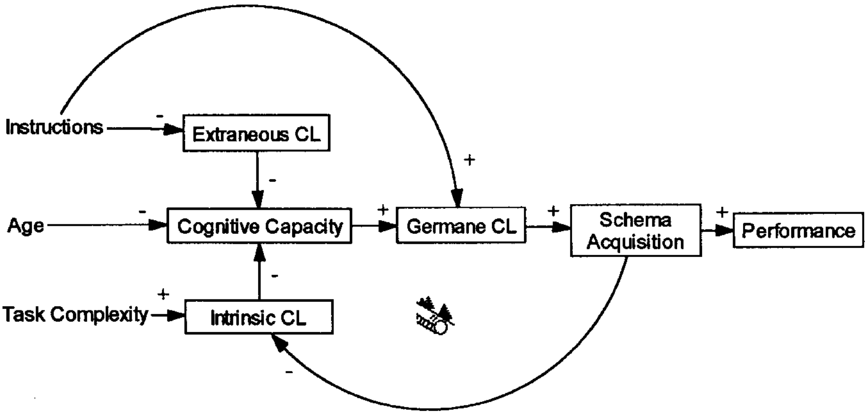

FIGURE 2 An integrative framework of cognitive load theory and cognitive aging.

The instructions variable, being either "conventional" or "CLT-based," in fact stands for the efficiency of the instructional format. How is this instructional efficiency reflected by other variables in the framework? An approach is to view efficiency as the ratio between extraneous CL and germane CL imposed on the learner. That is, the more efficient the instructions, the lower the level of extraneous CL and the higher the level of germane CL. Paas and Van Merriënboer (1993) determine instructional efficiency by representing an instructional format as a point in a diagram, whose position is determined by the z scores of the dimensions mental effort (M, on the x-axis) and performance (P, on the y-axis). Efficiency (E) is now defined as the perpendicular distance from this point to the line $P = M$, which can be expressed as:

$$E = \frac{P - M}{\sqrt{2}} \tag{1}$$

If performance P equals mental effort M, then efficiency E equals zero, which is to be interpreted as a neutral score. If $P > M$, then the instructions are efficient in that they apparently lead to a level of schema acquisition that minimizes the amount of mental effort needed for the task and at the same time maximizes the performance on that task. If $P < M$, however, then the performance is lower than can be expected on the basis of the invested amount of mental effort. In this case, the instructions are not efficient, because obviously they do not lead to a level of schema acquisition that is at least sufficient for an average performance. Mental effort is not incorporated in the present framework, but is reflected by the level of germane CL that is imposed on the available cognitive capacity.

Besides motivation (which is not included in the framework), the level of germane CL depends on the quality of the instructions. The instructions variable has a positive connection with germane CL and a negative connection with extraneous CL. If, in the case of conventional instructions, the efficiency is low, then extraneous CL is high and germane CL has a moderate level. If, however, in the case of CLT-based instructions, the efficiency is high, then the level of extraneous CL is minimized, whereas the level of germane CL is maximized. These are optimal conditions for the construction of cognitive schemata.

The age variable determines cognitive capacity. Cognitive capacity includes working-memory capacity, processing speed, and the ability to inhibit irrelevant information. These are all aspects of working memory. Thus, *cognitive capacity* can be defined as the maximum number of task-relevant items that can be stored and processed in working memory within a certain unit of time. In light of this definition, it is important that, especially in the case of reduced cognitive capacity, working memory is only occupied with effective operations on relevant information elements. After all, the amount of cognitive capacity that can be dedicated to schema acquisition is reduced by extraneous CL and intrinsic CL, so that it is essential to make maximal use of it. Thus, the cognitive capacity in the framework is the maximal capacity that can actually be claimed by germane CL.

In the framework, age neither affects extraneous CL, nor intrinsic CL. According to Paas and Van Merriënboer (1994a), however, age is a determining factor of cognitive load (see Figure 1). In their view, the concept can be interpreted as a sort of overall cognitive load which can be assessed by means of a subjective scale (e.g., Paas, Van Merriënboer, & Adam, 1993). This subjective or experienced cognitive load is high when the task and instructional demands (i.e., intrinsic CL and extraneous CL) are high and only little capacity is left for schema construction.

The level of intrinsic CL is determined by the complexity of the task. A task is complex when it contains relatively many interconnected elements. According to Sweller (1994), intrinsic CL has a fixed magnitude. That is, a task has a stable structure that requires a fixed set of cognitive operations. However, when schemata are constructed and become more refined and automated, less mental effort is needed for the same task (see Figure 1). In other words, intrinsic CL should gradually decrease. The system should thus contain a loop that affects the level of intrinsic CL. To track this loop, let us return to germane CL.

Germane CL is not only determined by the instructions. Its maximum value is confined by the available cognitive capacity. The instructions determine the extent to which this cognitive capacity is used. The more cognitive capacity, the more germane CL can be imposed on the learner. And the more germane CL is imposed, the more efficient is the schema-acquisition process. The loop is closed when the acquired schemata enhance the learner's performance as a result of decreased Intrinsic CL. Thus, we have an iterative process which accounts for the accumulation (symbolized by the rolling snowball in Figure 2), refinement, and automation of schemata, and, as a result of that, for a reduction of mental effort necessary for solving problems in a particular domain.

IMPLICATIONS OF COGNITIVE LOAD THEORY FOR ELDERLY LEARNERS

Since CLT-based instructions deal with cognitive limitations, they are likely to accommodate the mental abilities of elderly learners. In fact, CLT-based instructions optimally compensate for age-related cognitive declines. First, since limited working-memory capacity is the basic constraint CLT-based instructions deal with, more capacity becomes available for learning. Second, CLT-based instructions compensate the loss of information due to decreased processing speed. That is, if extraneous cognitive load is minimized, more relevant information elements can be processed within the same unit of time, so that less information will get lost. Moreover, the simultaneous activation of relevant information elements increases the chance of integration, and thus schema acquisition. Third, the problem of reduced inhibition can be bypassed, because redundant information will be left out as much as possible. Finally, CLT-based instructions present information such that the learner is directed to its essentials; for instance, by applying worked examples.

What can we now predict following the framework in Figure 2? To answer this question, let us perform a thought experiment with a group of young and a group of old adults. One half of both groups is presented with conventional instructions, the other half is presented with CLT-based instructions. Let us assume that the old adults have lost 20% of their original cognitive capacity. Let us further assume that both age groups initially experience equal levels of intrinsic CL in both conditions and that the level of extraneous CL, being equal for the age groups,* is reduced to 50% in the CLT condition. It thus follows that after deducting intrinsic CL and extraneous CL from the Total cognitive capacity, the elderly have less cognitive capacity left than the young, especially in the conventional condition. As a consequence, the elderly can devote less cognitive capacity to germane CL and thus to schema acquisition. Imagine that in the CLT condition the gain of cognitive capacity equals 50% of the initial extraneous-CL level for both age groups. Since the elderly have only 80% of the cognitive capacity of the young, their gain in cognitive capacity is proportionally more. The real benefit, however, lies in the proportion of germane CL. Formally this can be expressed as:

$$\frac{\Delta GCL}{TCC_{old}} > \frac{\Delta GCL}{TCC_{young}} \tag{2}$$

where ΔGCL symbolizes the absolute gain of germane CL and TCC the total cognitive capacity, that is the cognitive capacity *before* deducting intrinsic CL and extraneous CL. Given the assumption that ΔGCL proportionally takes effect in the performance of the learner, we can predict that the older group's performance will improve relatively more than the young group's performance.

In the critical situation where the level of cognitive load imposed by very complex tasks in combination with conventional instructions exceeds the total cognitive capacity of elderly learners, CLT-based instructions can reduce extraneous CL such that enough capacity becomes available for a full comprehension of the subject matter. Moreover, enough resources may become available for schema acquisition. In young learners it is more likely that the level of cognitive load remains within the limits of the total cognitive capacity. They also benefit from CLT-based instructions, but in their case it is not a question of whether or not the material is grasped, but rather to what extent it is grasped.

---

* It is not inconceivable that the levels of extraneous CL and intrinsic CL are, in fact, unequal for the age groups. If we consider, for instance, the inequality in the ability to reduce irrelevant information and we are dealing with a task in which such a competence is required, combined with an instructional format which contains a lot of redundant information, it becomes imaginable that the elderly would experience higher levels of both intrinsic CL and extraneous CL. As a matter of fact, this would strengthen the effect of CLT-based instructions relative to conventional instructions, because now there is even more extraneous CL to reduce in the elderly, providing them an extra advantage relative to the young. For the sake of simplicity and due to a lack of empirical literature, however, we have refrained from including a connection between age and extraneous or intrinsic CL in the framework.

The construction of schemata will eventually reduce the effort needed for a task, because a broader variety of problems can be tackled and the required mental operations are chunked into wholes (Paas & Van Merriënboer, 1994b). Although Sweller's (1994) definition of intrinsic CL may suggest invariability, it will eventually decrease, because its magnitude depends on the extent to which schemata are acquired. For elderly learners, a decrease in intrinsic CL will yield a substantial increase in the available cognitive capacity, paving the way for higher levels of germane CL and schema acquisition. Of course, both age groups will eventually exhibit enhanced performance, but since this enhancement is proportionally larger for elderly learners, the performance level of this group will grow towards the young group's performance level.

Finally, it should be noted that we have to differentiate between the acquisition of new knowledge and skills on the one hand, and the lifelong accumulation of knowledge and practicing of skills (i.e., crystallized abilities) on the other hand (e.g., Rabbitt, 1993). Despite a decline in the ability to acquire new schemata, the elderly have had many more years to automate their early-acquired schemata. These "old" schemata can of course be used to more than overcome their working-memory declines. After all, this is why the world values experience.

CONCLUSION

With cognitive load theory we have an important set of tools at our disposal which can be of great help in developing instructional material suiting the cognitive abilities of elderly learners. First, CLT is aimed at optimizing schema acquisition by stimulating an efficient use of working memory. Second, CLT makes it possible for elderly people to learn complex transfer-demanding skills, which are normally beyond their capabilities. Third, since CLT especially benefits the cognitive abilities of the elderly, it can lift their performance level towards the performance level of young adults, and thus reduce the gap between the age groups. Finally, because cognitive limitations play a significant role in the initial phase of acquisition, it is wise to present information with great care, at least at this stage. That is, especially when the cognitive demands are high, extraneous cognitive load should be minimized and learners should be motivated to invest mental effort for the acquisition of schemata. Once the instructions have persuaded the learner to take the plunge and rudimentary schemata have been acquired, subsequent steps will require less effort, motivation will grow, and knowledge will accumulate. For this reason, cognitive load theory can be considered as an essential guide.

REFERENCES

Allen, P. A. (1990). Influence of processing variability on adult age differences in memory distribution of order information. *Cognitive Development*, *5*, 177–192.

Allen, P. A., Madden, D. J., Groth, K. E., & Crozier, L. C. (1992). Impact of age, redundancy, and perceptual noise on visual search. *Journal of Gerontology: Psychological Sciences*, *47*, 69–74.

Baddeley, A. (1992). Working memory. *Science*, *255*, 556–559.

Bobis, J., Sweller, J., & Cooper, M. (1993). Cognitive load effects in a primary-school geometry task. *Learning and Instruction*, *3*, 1–21.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of introduction. *Cognition and Instruction*, *8*, 293–332.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology*, *62*, 233–246.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review*, *3*, 149–210.

Czaja, S. J., & Sharit, J. (1993). Age differences in the performance of computer-based work. *Psychology and Aging*, *8*, 59–67.

Einstein, G. O., Smith, R. E., McDaniel, M. A., & Shaw, P. (1997). Aging and prospective memory: The influence of increased task demands at encoding and retrieval. *Psychology and Aging*, *12*, 479–488.

Fisk, J. E., & Warr, P. (1996). Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. *Psychology and Aging*, *11*, 316–323.

Gilinsky, A. S., & Judd, B. B. (1994). Working memory and bias in reasoning across the life span. *Psychology and Aging*, *9*, 356–371.

Hartmann, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging*, *6*, 587–594.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193–225). San Diego: Academic Press.

Horn, J. L., & Cattell, R. B. (1967). Age difference in fluid and crystallized intelligence. *Acta Psychologica*, *26*, 107–129.

Kidder, D. P., Park, D. C., Hertzog, C., & Morrell, R. W. (1997). Prospective memory and aging: The effects of working memory and prospective memory task load. *Aging, Neuropsychology, and Cognition*, *4*, 93–112.

Lorsbach, T. C., & Simpson, G. B. (1988). Dual-task performance as a function of adult age and task complexity. *Psychology and Aging*, *3*, 210–212.

Madden, D. J., Connelly, S. L., & Pierce, T. W. (1994). Adult age differences in shifting focused attention. *Psychology and Aging*, *9*, 528–538.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology*, *90*, 312–320.

Morris, J. M. (1994). Computer training needs of older adults. *Educational Gerontology*, *20*, 541–555.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology*, *87*, 319–334.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review*, *97*, 475–487.

Paas, F. G. W. C. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, *84*, 429–434.

Paas, F. G. W. C., & Van Merriënboer. J. J. G. (1993). The efficiency of instructional conditions: An approach to combine mental effort and performance measures. *Human Factors*, *35*, 737–743.

Paas, F. G. W. C., & Van Merriënboer, J. J. G. (1994a). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review*, *6*, 351–371.

Paas, F. G. W. C., & Van Merriënboer, J. J. G. (1994b). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology*, *86*, 122–133.

Paas, F. G. W. C., Van Merriënboer, J. J. G., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills*, *79*, 419–430.

Penney, C. G. (1989). Modality effects and the structure of short-term verbal memory. *Memory & Cognition*, *17*, 398–422.

Rabbitt, P. M. A. (1993). Crystal quest: A search for the basis of maintenance of practiced skills into old age. In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control: A tribute to Donald Broadbent* (pp. 188–230). Oxford, UK: Clarendon Press/Oxford University Press.

Salthouse, T. A. (1993). Speed mediation of adult age differences in cognition. *Developmental Psychology*, *29*, 722–738.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*, 403–428.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, *27*, 763–776.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257–285.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology*, *81*, 457–466.

Sweller, J. (1993). Some cognitive processes and their consequences for the organisation and presentation of information. *Australian Journal of Psychology*, *45*, 1–8.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*, 295–312.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Institution*, *12*, 185–233.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General*, *119*, 176–192.

Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction*, *2*, 59–89.

Sweller, J., & Levine, M. (1982). Effects of goal specificity on means-ends analysis and learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8*, 463–474.

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251–296.

Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When two sensory modes are better than one. *Journal of Experimental Psychology: Applied, 3*, 257–287.

Van Gerven, P. W. M., Paas, F. G. W. C., & Van Merriënboer, J. J. G. (1998, April). *Instructional efficiency: Relations between cognitive load, task complexity, and aging*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Van Merriënboer, J. J. G., & Paas, F. G. W. C. (1990). Automation and schema acquisition in learning elementary computer programming: Implications for the design of practice. *Computers in Human Behavior, 6*, 273–289.

Ward, M., & Sweller, J. (1990). Structuring effective worked examples. *Cognition and Instruction, 7*, 1–39.

Welford, A. T. (1985). Changes of performance with age: An overview. In N. Charness (Ed.), *Aging and human performance* (pp. 333–365). New York: Wiley.

Wingfield, A., Stine, E. A. L., Lahar, C. J., & Aberdeen, J. S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research, 14*, 103–107.