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REVIEW ARTICLE

Toward a Synthesis of Cognitive Load Theory, Four-Component Instructional Design, and Self-Directed Learning

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Abstract This article explores the opportunities to apply cognitive load theory and four-component instructional design to self-directed learning. Learning tasks are defined as containing three elements: learners must (a) *perform* the tasks, (b) *assess* their task performance, and (c) *select* future tasks for improving their performance. Principles to manage intrinsic and extraneous load for performing learning tasks, such as simple-to-complex ordering and fading-guidance strategies, are also applicable to assessing performance and selecting tasks. Moreover, principles to increase germane load, such as high variability and self-explanation prompts, are also applicable to assessment and selection. It is concluded that cognitive load theory and four-component instructional design provide a solid basis for a research program on self-directed learning.

Keywords Cognitive load theory

A tendency in modern education is to use rich learning tasks, which are based on real-life situations from daily or professional life, as a basis for complex learning (van Merriënboer 2007; van Merriënboer and Kester 2007; van Merriënboer *et al.* 2003). The central idea is that such tasks stimulate learners to integrate the knowledge, skills, and attitudes that underlie the performance of realistic tasks, and so help them construct a knowledge base that allows for transfer of what is learned to solving new problems in unfamiliar situations. A risk of this approach, however, is that the cognitive load imposed by the learning tasks is often excessive for novice learners and may seriously hamper learning.

Cognitive load theory (Sweller 1988; Sweller *et al.* 1998; van Merriënboer and Sweller 2005) and the four-component instructional design model (4C/ID-model; van Merriënboer

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et al. 1992; van Merriënboer 1997; van Merriënboer *et al.* 2002a; van Merriënboer and Kirschner 2007) provide guidelines for lowering the cognitive load associated with learning from rich tasks. Over the last 20 years, these concordant theories have developed in a complimentary fashion, with cognitive load theory focusing on the design of instructional materials and 4C/ID focusing on the design of educational programs. Both theories distinguish three types of cognitive load: intrinsic cognitive load, which is determined by the complexity of the learning tasks (i.e., the amount of interacting elements that have to be processed simultaneously); extraneous cognitive load, which is caused by suboptimal instructional design and associated processes that do not contribute to learning (e.g., dealing with split attention and redundancy), and germane cognitive load, which is caused by appropriate instructional design and associated processes that directly contribute to learning (e.g., induction, elaboration).

In the case of complex learning environments, effective methods to decrease cognitive load include, for example, simple-to-complex ordering and scaffolding performance. Simple-to-complex ordering of whole tasks may be reached by gradually expanding the number of interacting elements in these tasks. Early in the learning process, *intrinsic* load is largely determined by low element interactivity combined with low expertise of the learners, whereas later in the learning process, intrinsic load is at a comparable relative level but determined by higher element interactivity combined with higher expertise of the learners. High-expertise learners possess cognitive schemas that allow them to treat a set of interrelated elements as one single element. Consequently, as expertise develops, learners are able to cope with higher element interactivity. Scaffolding performance helps to prevent high *extraneous* cognitive load, and possible overload, by decreasing support and guidance as learners acquire more expertise (i.e., fading; Kester *et al.* 2007).

The drawback of established approaches to lower learners' cognitive load in environments for complex learning is twofold. First, they typically yield a sequence of learning tasks that are identical for the whole target group, not leaving room for the adaptation of learning tasks to the needs of individual learners (Kalyuga 2006). Second, the use of a predetermined sequence of learning tasks leaves little opportunity for self-directed learning. The lack of flexibility in the educational program makes it difficult for learners to (a) take full responsibility for performing learning tasks, (b) assess the strengths and weaknesses in their own performance, and (c) select learning tasks that offer the best opportunities to remediate weaknesses and improve performance. Self-directed learning is central to lifelong learning in a society that is characterized by fast technological changes and knowledge and skills that quickly become obsolete (Field 2006). Therefore, future research should contribute to the design of environments that allow for self-directed learning, and which preferably do so in a way that improves the ability of learners to perform, assess, and select tasks that best fulfill their personal needs.

The main goal of this article is to investigate what cognitive load theory and four-component instructional design might contribute to research on the design of environments for self-directed learning. In the first section, implications of self-directed learning for the nature of learning tasks and the organization of these tasks are discussed. In the second section, guidelines for reducing high cognitive load resulting from performing rich learning tasks will also be extended to include guidelines for reducing high cognitive load resulting from the learners assessing their own performance and selecting new tasks. In the third section, guidelines that help learners explicitly devote their freed-up processing resources to learning processes that evoke a *germane* cognitive load are discussed. In the final section, a discussion of the presented theoretical framework is provided, and directions for future research are given.

Self-Directed Learning and the Nature of Learning Tasks

Van Merriënboer's 4C/ID-model (van Merriënboer *et al.* 1992; van Merriënboer 1997; van Merriënboer *et al.* 2002a; van Merriënboer and Kirschner 2007) is fully consistent with cognitive load theory, although it focuses more on the design of educational programs (i.e., courses and curricula) and less on the design of instructional materials. The basic claim of 4C/ID is that all environments for complex learning can be described in terms of four interrelated components: (1) learning tasks, (2) supportive information, (3) procedural information, and (4) part-task practice. Learning tasks are meaningful whole tasks, based on real-life tasks from professional or daily life and typically require the integrated use of knowledge, skills, and attitudes. Supportive information helps learners to perform the problem-solving and reasoning aspects of these tasks. Procedural information points out to learners how to perform the routine aspects of such tasks. Part-task practice is additional practice to develop routine aspects of the tasks to a very high level of automaticity. The theoretical framework presented in this article is limited to the learning tasks because they provide the backbone of an educational program to which the other three components are connected. Obviously, learners cannot immediately be confronted with highly complex learning tasks. This would overwhelm their cognitive resources and might have other negative effects, such as jeopardizing their motivation. Therefore, learning tasks should be organized from simple to complex or from easy to difficult. In addition, support and guidance for task performance should be high in the beginning and gradually fade away in a process of scaffolding. The next sections discuss the model for organizing learning tasks and an elaborated version of this model for self-directed learning.

A model for organizing learning tasks

Simple-to-complex sequencing is only necessary if after the removal of all sources of extraneous cognitive load, the load imposed by the task is still too high to allow learning. In this situation, the element interactivity of the task should be reduced by reducing the number of elements and interactions between elements, which must be dealt simultaneously in order to complete the task (Ayres 2006; Pollock *et al.* 2002; see also van Merriënboer and Sweller 2005). The 4C/ID-model organizes learning tasks in so-called "task classes" to reach this goal. In the upper part of Fig. 1, learning tasks that learners perform (P = Performance) are indicated by circles, and tasks classes are indicated by the dotted boxes enclosing a number of learning tasks. In the first task class, learning tasks deal with only part of the relevant elements and interactions between those elements. Yet, they are representative of the simplest real-world whole tasks. Learning tasks within the same task class are equivalent to each other, meaning that they can be performed on the basis of the same—general or abstract—knowledge. However, their main features differ from each other in the same way real-world tasks differ. Each subsequent task class expands the number of interacting elements the learner must take into account but keeps intrinsic cognitive load at a manageable level because learners are able to deal with more and more interacting elements due to their increasing expertise (see van Merriënboer and Kirschner 2007, for a description of different techniques for simple-to-complex ordering).

With regard to scaffolding, extraneous cognitive load can be reduced by providing support and guidance when learners start to work on more difficult tasks (i.e., in the beginning of a new task class). Support and guidance should prevent learners from paying attention to irrelevant task aspects. In Fig. 1, the filling of the circles indicates the level of support and guidance provided to the learners. As learners acquire more expertise, support

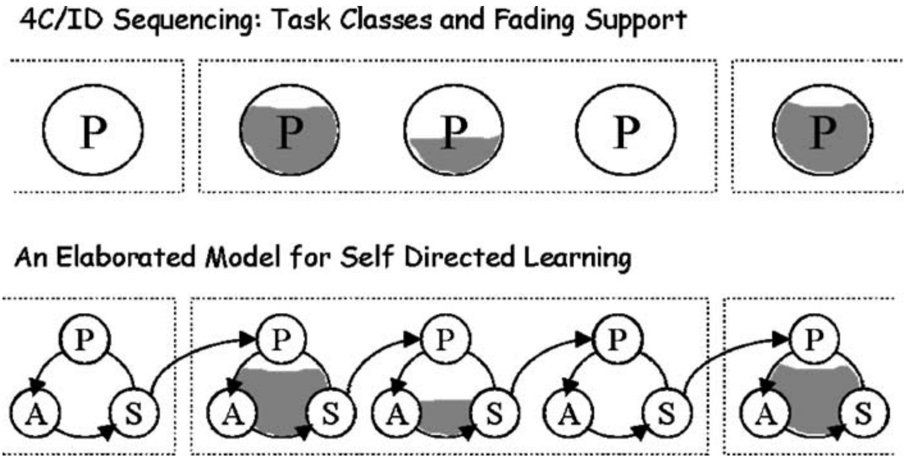

Fig. 1 Ordering learning tasks according to **a** the 4C/ID-model with task classes and fading support (upper part), and **b** an elaborated model for self-directed learning with performance (*P*), assessment (*A*), and selection (*S*) as well as dynamic links between tasks (*lower part*)

and guidance is gradually decreased until learners are able to perform the learning tasks independently, without any support or guidance. Then, learners may continue with the performance of more difficult tasks (i.e., a next task class), for which they initially receive a high level of support and guidance again. In the context of cognitive load theory and 4C/ID, the *completion strategy* is probably the most familiar example of a highly effective fading-guidance strategy that might be applied within one task class (for an overview, see Renkl and Atkinson 2003). In this strategy, three phases are distinguished. In the first stage, the learning tasks take the form of worked examples the learners must study or analyze. In the second stage, learning tasks take the form of completion tasks with increasingly more incomplete solutions that learners must finish. Only in the final stage are conventional tasks used for which learners must independently generate solutions.

An elaborated model for self-directed learning

A shift to self-directed learning has two important implications for the structure of an educational program as depicted in the upper part of Fig. 1. The first concerns the nature of the whole tasks: prevailing models of self-directed learning (e.g., Boekaerts and Cascallar 2006; Butler and Winne 1995; Zimmerman 2002) stress that these tasks should at least evoke the self-regulative processes of monitoring, evaluating, and planning. Monitoring focuses on the learner's ability to keep track of progress toward the goal(s) of the task. Evaluating involves the ability to assess the results of the task, the process of performing the task, and the achievement of set goals. Planning focuses on setting readjusted or new goals, selecting suitable strategies of achieving these goals, and identifying as well as dealing with possible obstacles to attaining the goals.

In accordance with models of self-directed learning, whole tasks in our model no longer solely pertain to "performing" a task in order to acquire domain-specific skills. In addition, they also confront the learner with the need to assess his or her own performance and to select future learning tasks that might help to improve performance (see lower part of Fig. 1; P = Performance, A = Assessment, S = Selection). The main aim of the assessment process (in the lower part of Fig. 1, the small circles with the A included) is to identify learning needs through a critical reflection on previous task performance in relation to agreed standards for acceptable performance (What did I do? What went right or wrong?). The main aim of the selection process (in the lower part of Fig. 1, the small circles with the S included) is to identify appropriate future learning tasks, through a critical "preflection" on future task performance in relation to the fulfillment of identified learning needs (What should I do next? How could that help me to improve performance?). Thus, learners eventually take responsibility over the whole learning cycle, including performance of the learning tasks, assessment of the quality of own task performance, and selection of future tasks that optimally contribute to further learning.

The second related change pertains to the dynamic links between learning tasks (i.e., the connecting arrows between learning tasks in the lower part of Fig. 1), meaning that the results obtained on earlier tasks affect the selection of later tasks. The dynamic planning of learning tasks becomes possible because the main aim of the assessment process is no longer to provide corrective feedback and to make pass/fail decisions, but to compare the quality of performance over time (i.e., ipsative assessment) and to formulate learning needs. This enables the planning of an individual learning trajectory, or, the iterative selection of new learning tasks that are dependent on individual assessment results. For instance, if assessment results indicate one is able to perform supported learning tasks, the learner may select a next learning task with less support or guidance. If results indicate one is not yet able to perform supported learning tasks, the learner may select a next learning task with a similar amount of support and guidance (i.e., additional practice) or with specific help on aspects of performance that yet need to be improved. If results indicate one is able to independently perform unsupported learning tasks, the learner may select more difficult learning tasks (i.e., proceed to a next task class). Consequently, there is not a single curriculum for all learners, but each learner is free to plan his or her own curriculum (i.e., on-demand education). One learner may quickly proceed from task class to task class and mainly work on learning tasks with limited or no support, while another learner may need much more time to progress from task class to task class and mainly work on tasks with sizeable support.

Enabling Self-Directed Learning: Decreasing Cognitive Load

Learners are not able to perform complex learning tasks right from the start of an educational program because their cognitive resources will be overwhelmed. Therefore, simple-to-complex ordering and/or scaffolding through fading-guidance strategies can be applied to manage both intrinsic and extraneous load. In the system of self-directed learning described in the previous section (see the lower part of Fig. 1), the same is true for the assessment of task performance and the selection of future learning tasks. The main claim of this article is that the cognitive load principles and associated instructional methods to promote the acquisition of domain-specific skills are also useful to simultaneously promote the development of self-assessment and task selection skills.

Self-assessment skills

In order to promote reflection on past performance, learners receive whole and meaningful assessment tasks right from the start of the educational program. Such tasks ask learners to assess the quality of their performance in relation to agreed standards so that they can formulate readjusted or new learning needs. Task performance should be assessed on a typically large set of qualitatively different aspects (e.g., routine aspects, problem-solving and reasoning aspects, social aspects) which are interrelated. As for task performance, simple-to-complex ordering may be used to manage the intrinsic cognitive load associated with the self-assessment task. For example, a first task class may only deal with routine aspects, a second task class with routine aspects as well as problem-solving aspects, and a final task class with routine, problem-solving, and social aspects. For teaching medical diagnosis, this could mean that learners who are practicing medical interviews deal with the assessment of routine aspects of their behaviors (e.g., taking blood samples) and related criteria in terms of speed and accuracy in a first task class. In a second task class, they deal with the assessment of routine as well as problem-solving aspects (e.g., dealing with failing apparatus) and related values such as working procedures and conventions. Finally, in a third task class, they deal with the assessment of routine, problem-solving, as well as social aspects and related desired attitudes (e.g., being friendly to patients).

In each separate task class, fading-guidance strategies may be used to manage extraneous cognitive load. Such strategies do not affect the number of interacting elements in the task (i.e., intrinsic load), but help learners focus their attention on those aspects that are most relevant in a particular stage of the learning process. An example of the completion strategy applied to the assessment component of a learning task would, for instance, first present the learners with fully worked-out examples of well-conducted assessments, then with incomplete worked-out examples of assessments that must be completed by the learners, and finally with conventional self-assessment tasks where learners should independently assess the quality of their own performance. Consequently, there is a gradual transition from *being assessed* to *self-assessment* in each task class. A teacher or other intelligent agent may present the fully worked-out examples and provide an exemplary assessment of all relevant aspects of performance, using all relevant standards (e.g., criteria, values, attitudes) and clearly specifying identified learning needs and points of improvement. Incomplete examples might provide the learners with critical parts of the assessment, such as a list with relevant standards or useful scoring rubrics. Finally, the conventional assessment tasks require the learners to self-assess their performance independently—without any external support or guidance.

Task selection skills

With regard to preflection on future performance and the selection of learning tasks with characteristics (e.g., difficulty, available support, particular surface, or structural features) that help to fulfill identified learning needs, learners should have the opportunity to plan their own learning trajectory to a smaller or greater degree. Many aspects of available learning tasks are relevant to answering the question if they will help to fulfill current learning needs or not. To name just a few, relevant aspects include task difficulty (i.e., to which task class it belongs), available support and guidance during performance, and all other features on which tasks differ from each other in the real world. Such task features may affect either the way the task needs to be performed (structural features) or not (surface features). As for performing the task and assessing the quality of task performance, simple-to-complex ordering may be used to manage the intrinsic cognitive load associated with the selection of future tasks. For example, a first task class may ask the learner to deal only with aspects related to available support and guidance. A second task class may ask the learner to deal with aspects related to available support and guidance as well as task difficulty. A final task class may ask the learner to deal with all aspects related to support and guidance, difficulty, as well as structural and surface features. Thus, while the learner has to select suitable learning tasks right from the start of the educational program, the number of aspects or interacting elements that needs to be simultaneously taken into account is gradually increasing.

In each task class, scaffolding methods may subsequently be used to manage extraneous cognitive load. Corbalan *et al.* (2006) describe "shared control" as a promising way to reach this goal. Shared control is a two-step process, in which the teacher or other intelligent agent first selects from all available learning tasks a subset of tasks with characteristics that fit the needs of the individual learner (e.g., Salden *et al.* 2006a,b). This should prevent overwhelming the learner by letting him or her choose from a very large set of tasks. Second, the learner selects from this subset one task to work on. The subset of preselected tasks is small in the beginning of a task class. Then, the size of the subset gradually increases until the learner selects one task out from all available tasks. Consequently, there is a gradual transition from *having the tasks selected for you* to *selecting your own tasks* in each task class. In an electronic learning environment with learning tasks in the genetics domain, shared control over task selection had superior effects on transfer test performance and task involvement—provided that learners had to choose from a subset of preselected tasks with surface features that were different from the surface features of previous tasks (Corbalan *et al.* 2008a). With learning tasks in the dietetics domain, Corbalan *et al.* (2008b) found that shared control over task selection also led to higher task involvement than program control, that is, higher learning outcomes combined with more effort directly invested in learning (for more detail on the computation of task involvement, see Paas *et al.* 2005).

Reinforcing Self-Directed Learning: Increasing Germane Load

The exemplary methods to manage intrinsic and extraneous cognitive load described in the previous section may be applied in their own right, namely, to prevent cognitive overload of the learner. But an equally important goal is to free up cognitive resources that may subsequently be devoted to genuine learning, that is, to processes of schema construction and schema automation generating *germane* cognitive load (van Merriënboer *et al.* 2006; van Merriënboer *et al.* 2002b). In the context of cognitive load theory and 4C/ID, most research on instructional methods promoting germane cognitive load has been dealing with variability of learning tasks (e.g., Paas and van Merriënboer 1994; Quilici and Mayer 1996) and self-explanation and reflection prompts (e.g., Renkl 1997; Stark *et al.* 2002; van den Boom *et al.* 2004,2007). In the context of self-directed learning, similar methods might be developed to reinforce the learning of self-assessment and task selection skills.

Self-assessment skills

With regard to the reinforcement of learning self-assessment skills, the use of 360-degree feedback is probably the best example of the benefit of variability (e.g., Bracken *et al.* 2001). The term 360-degree feedback was developed in the field of human resource development and refers to the combined use of assessments from different sources such as peers, managers, and clients. Self-assessments may also be included. Compared to traditional assessments in education, where only one teacher assesses the learners, 360-degree feedback typically gives more elaborated information to the learners. More standards for acceptable performance are taken into account, and different assessors will usually give different weights to those standards. If nevertheless different assessors come to the same conclusions, the credibility of those conclusions increases. Therefore, such feedback provides learners with a more solid basis to plan their training and development.

The use of self-explanation or reflection prompts in relation to the assessment of learning tasks is easy to combine with 360-degree feedback. Learners are explicitly prompted to compare and contrast the similarities and dissimilarities between different assessments (possibly including self-assessments), yielding a more complete picture of what different assessors see as weak and strong points of their performance. Another way to stimulate learners to self-explain the principles governing good assessments is to have them assess the performance of their peers (Sluijsmans *et al.* 2001). Peer assessment forces learners not only to detect and formulate the weak and strong aspects of their peers' performance, but also to explain *why* particular assessments are made in order to make them acceptable for their peers. For instance, assessments might be justified by explicitly linking observed behaviors to agreed standards for acceptable performance (Sluijsmans *et al.* 2002; Sluijsmans *et al.* 2004). Combined with a fading-guidance strategy, peer assessment could then provide a valuable intermediate stage between studying the assessments of one's own performance made by others (i.e., worked-out examples) and self-assessing this performance (Sluijsmans *et al.* 2003). Finally, with regard to self-assessments, learners could be prompted to provide deep explanations for the weak and strong aspects of their performance. For instance, asking learners to diagnose whether weak aspects of behavior are due to missing knowledge, insufficient practice, or misconceptions might help them identify causes for suboptimal performance and come up with remediation strategies. Obviously, a more accurate diagnosis of causes for performance problems is helpful to the selection of new learning tasks that contribute to further learning.

Task selection skills

With regard to reinforcing the learning of task selection skills, variability might be realized by asking learners to combine assessments of the performance of peers with giving them advice on their learning trajectories. Conducting assessments and making task selections for peers typically yields a higher variability than self-assessments and own task selections, and is therefore expected to make the principles for task selection more salient. Task selections should vary from each other with regard to principles such as, for instance:

- If all performance standards are met on tasks with support and guidance, then new tasks should be selected with less support and guidance;
- if all performance standards are met on tasks without support and guidance, then new tasks should be selected that are more difficult;
- if not all performance standards are met on tasks with support and guidance and there are specific points for improvement, then new tasks should be selected with specific support (e.g., explanations, guiding questions) for those points, or
- if not all performance standards are met on tasks with support and guidance but there are no specific points for improvement, then new tasks should be selected with equal support and guidance to continue practicing.

In combination with a fading-guidance strategy to reduce extraneous cognitive load, learners would first study such principles in task selections made for them by others (e.g., their teacher or coach) and act upon them, then use the principles to give advice to peers of whom they assessed performance, and finally make task selections for their own.

Finally, self-explanation or reflection prompts may be combined with practicing the selection of learning tasks. Basically, learners are then asked to reflect on task selections and to make the applied principles explicit, by answering questions such as "why did you decide to work on a learning task that is much more difficult than the previous tasks you worked on?" or "did the selected task(s) help you to reach a better understanding of the learning domain and remediate your misconceptions?" In on-demand education, supervision meetings are often used to help learners self-explain their behaviors (van der Klink *et al.* 2001). In such regular meetings, a supervisor discusses with the learner the strong and weak points in his or her assessments (i.e., assessing the self-assessments), the degree to which performed learning tasks helped to fulfill the individual learning needs, and the planning of the future learning trajectory. Thus, supervision meetings help learners to self-explain the relationships between self-assessment results on the one hand, and characteristics of newly selected learning tasks on the other hand.

Discussion

In this article, we explored opportunities to apply cognitive load theory and 4C/ID to the field of self-directed learning. In order to do so, a new vision on learning tasks is necessary: A "whole" learning task no longer refers to solely performing this task, but also to assessing the quality of performance to identify learning needs and to selecting future learning tasks that are suitable to fulfill those needs. Characteristic of the presented approach is that self-directed learning skills are always taught in the context of training domain-specific complex skills—they are never taught in isolation. But if domain-specific skills and self-directed learning skills are taught in a combined fashion, known principles to reduce cognitive load while performing complex learning tasks, such as simple-to-complex ordering and fading-guidance strategies, are also useful to enable self-directed learning skills (i.e., assessing own task performance and selecting future tasks). Furthermore, known principles to increase germane load for performing complex learning tasks, such as high variability and self-explanation prompts, are also useful to reinforce those self-directed learning skills. Concluding, our analysis shows that cognitive load theory and 4C/ID provide a strong basis for a research and development program on self-directed learning.

An important limitation of the current study is its exclusive focus on the organization of learning tasks. According to the 4C/ID-model, three other necessary components for the teaching of complex skills are supportive information, procedural information, and part-task practice. We argue that the same three components are required for the teaching of self-directed learning skills, but it is yet an open question if for each of those three components the instructional methods for teaching domain-specific skills can be "translated" to teaching self-directed learning skills. This is an important next step for future research, in which the presented theoretical framework for self-directed learning should be broadened to include, in addition to learning tasks, the supportive information, procedural information, and part-task practice for teaching self-directed learning skills.

With regard to measurements, the presented framework also points out some future research directions. First, cognitive load researchers often use overly simplified measures of complex performance, such as one single score on a transfer test. In future research, it is important to assess task performance in a more detailed fashion, taking different standards (e.g., criteria, values, attitudes) for different aspects of performance (e.g., routines, problem-solving and reasoning aspects, social skills) into account (Sluijsmans *et al.* 2008). Such detailed measurements are necessary to refine the analysis and teaching of self-directed learning skills. Second, cognitive load research should pay more attention to self-monitoring the development of expertise over time. Performed learning tasks and associated assessment results may be registered in a personal history profile (Zimmerman 1990) or digital development portfolio (Kicken *et al.* 2008). The information in such a profile or portfolio provides a sound basis for dynamic task selection by the self-directed learner, another intelligent agent (e.g., Kalyuga, 2006; Salden *et al.* 2006a,b), or a combination of both (i.e., shared control, Corbalan *et al.* 2006).

To conclude, research on cognitive load theory and 4C/ID has generated many principles and associated instructional methods to promote complex learning. Those methods have been applied in a wide variety of educational programs for the training of complex cognitive skills, and proved useful to increase the quality and outcomes of these programs (van Merriënboer and Kirschner 2007). As a next step, cognitive load theory and 4C/ID may provide a fruitful framework for a research program on self-directed learning, which is becoming more and more important as a condition for lifelong learning in modern society.

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