Proceedings of the e-Skills for Knowledge Production and Innovation Conference 2014

Cite as: Kalyuga, S. (2014). Managing cognitive load when teaching and learning e-skills. *Proceedings of the e-Skills for Knowledge Production and Innovation Conference 2014, Cape Town, South Africa,* 155-160. Retrieved from http://proceedings.e-skillsconference.org/2014/e-skills155-160Kalyuga693.pdf

Managing Cognitive Load When Teaching and Learning e-Skills

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Abstract

The paper introduces major categories of cognitive load imposed on learners in instructional situations and provides examples of methods for managing different types of load when teaching and learning such e-skills as using new software manuals and using spreadsheets. It describes three series of studies within a cognitive load framework that illustrate methods for reducing unnecessary, wasteful extraneous cognitive load (split-attention and redundancy effects), managing essential, productive intrinsic cognitive load (pre-training and isolated elements effect), and appropriately focusing working memory resources by enhancing germane resources (imagination effect).

Keywords: cognitive load, split-attention, redundancy, pre-training, isolated elements technique, imagination technique.

Introduction

According to cognitive load theory, two major components of our cognitive architecture that are critical to learning are long-term memory and working memory (for overviews of this architecture and cognitive load theory, see Kalyuga, 2011, and Sweller, Ayres, & Kalyuga, 2011). The permanent knowledge base in long-term memory is critical in most of human cognitive activities including learning. This organized knowledge base could be conceptualized as generic knowledge structures (schemas) representing concepts and procedures that allow us to categorize problem situations.

Working memory is another major component of our cognitive architecture that, according to the above model of human cognitive architecture, represents a mechanism that limits the scope of immediate simultaneous changes to the knowledge base in long-term memory that may potentially inhibit its functionality (Sweller et al., 2011). Working memory is also associated with conscious processing of information within the focus of attention. Its processing capacity and duration are severely limited to only several units of information at a time when dealing with novel information (Cowan, 2001; Miller, 1956). Had the number of new simultaneously processed elements of information not been limited by the capacity of working memory, effective decisions in new situations would have been unlikely because of an overwhelming combinatorial explosion caused by the need of considering all possible interrelations between many elements.

This paper accepted and published after external peer-review

From this perspective, the importance of the learner organized knowledge base in long-term memory is primarily determined by its ability to effectively reduce the capacity limitation of working memory by encapsulating many elements of information into higher-level chunks that could be treated as single units in working memory (Ericsson & Kintsch, 1995). Learners with higher levels of prior knowledge heavily rely on this mechanism in order to reduce their cognitive load. Another critical means of reducing cognitive load is the automation of basic procedures to the point at which they do not require any controlled conscious processing in working memory.

Cognitive load theory distinguishes two major types of cognitive load that must be managed in any learning situation. Extraneous cognitive load is the burden unnecessarily imposed on working memory by poor instructional design. Ideally, this load should be eliminated or reduced as much as possible to enhance learning. Intrinsic cognitive load, on the other hand, is essential for learning load caused by the innate complexity (levels of interactivity or interconnectedness between the elements of information) of the instructional material relative to the level of learner prior knowledge. This load needs to be appropriately managed (reduced or increased depending on the magnitude of total cognitive load and available working memory resources). An efficient instructional design needs to keep the total of the extraneous and intrinsic cognitive load below the capacity limits of working memory allowing effective learning to take place. Working memory resources actually allocated by the learner to dealing with productive intrinsic cognitive load are defined as germane resources or germane cognitive load (Sweller, 2010).

The following sections of the paper describe three series of studies within a cognitive load framework associated with the acquisition of e-skills (e.g., learning new computer software from manuals or learning how to use spreadsheets) that illustrate methods for reducing unnecessary (wasteful) extraneous cognitive load, managing essential (productive) intrinsic cognitive load, and appropriately focusing working memory resources (enhancing germane resources).

Reducing Extraneous Cognitive Load (Split-attention and Redundancy Effects)

The split-attention and redundancy situations can be found in many instructional materials used in learning e-skills. For example such situations could be created by manuals that come with various software products from which many e-skills are acquired in the first place (either in printed forms or presented as on-screen instructions). These manuals usually require following the instructions immediately on the actual computer thus causing learners to split their attention between the manuals, computer screen and keyboard. The associated search-and match processes may result in a heavy extraneous cognitive load that do not contribute to learning but consume limited working memory resources.

In addition, using the diagrams of a computer screen in the manual and the computer itself may generate a redundancy effect because of the need for learners to process the redundant source of information. Eliminating the computer and using only the diagrams of the computer screen and keyboard with physically integrated textual explanations could be an effective technique during the initial stages of instruction. Sweller and Chandler (1994) and Chandler and Sweller (1996) demonstrated benefits of learning from such manuals with integrated diagram and text instructions without using the actual computers for technical apprentices who showed superior performance and reduced learning times compared to their peers learning from traditional instructional materials with computers. Even more importantly, these learners performed better not only in written but also in practical skill posttests despite the absence of any practical exercises with actual computers before the tests. Cerpa, Chandler, and Sweller (1996) also demonstrated that placing instructions only on a computer screen was more effective than having them on the screen and in a manual simultaneously because of the extraneous cognitive load caused by redundant information.

It should be noted that the complexity of learning materials (high levels of element interactivity) is an essential factor of this effect (as most other cognitive load effects). Only for such complex materials, an additional extraneous cognitive load caused by processing redundant information could exceed working memory capacity limits. For simple materials, the resulting cognitive load may still be within working memory limits and not interfere with learning (Chandler & Sweller, 1996).

Thus, temporarily eliminating computers at the initial stages of learning particular software skills and using self-contained manuals could facilitate acquisition of these skills for novice learners. Alternatively, placing all the relevant information on the computer screen instead of the manual may also be an effective approach (computer is used only as a page-turner in this case). During the following stages of learning, the computer could be used for performing or practicing the relevant skills, since the learners would acquire some knowledge by that time that would enable them to cope with higher levels of cognitive load.

Managing Intrinsic Load (Pre-training and Isolated Elements Effects)

High levels of intrinsic cognitive load are caused by interconnected elements of information that must be processed simultaneously in order to be understood (i.e. materials with high levels of element interactivity). The required cognitive resources for processing such information may exceed the available working memory capacity, especially for novice learners who need to process simultaneously all the individual elements of information and their connections in working memory. While extraneous cognitive load could be reduced by using appropriate instructional design techniques, changing intrinsic load requires changing the whole learning task or/and changing the level of learner prior knowledge. The learners with higher levels of domain specific knowledge are capable of processing a larger number of interacting elements simultaneously without a cognitive overload because they can incorporate many such elements into a single chunk that could be treated as a single element in working memory.

Since intrinsic cognitive load always depends on learner levels of prior knowledge, one obvious method of reducing intrinsic load is to develop specific prerequisite knowledge before the main instructional materials are presented. This method is often referred to as pre-training. For example, Clarke, Ayres and Sweller (2005) investigated the effectiveness of pre-training basic spreadsheet skills that were required for learning specific mathematical concepts (graphs) and found that students with low knowledge of spreadsheets benefited from such pre-training compared with students who were simultaneously dealing with the spreadsheets and mathematical concepts. However, the technique was redundant for more knowledgeable learners who already had many schemas associated with spreadsheets. Thus, the effectiveness of the pre-training method depends on levels of learner prior experience in the corresponding domain.

Blayney, Kalyuga and Sweller (2010) investigated the effectiveness of altering the nature of the task (an isolated-elements method) with undergraduate university accounting students learning how to construct spreadsheet formulae for basic accountancy concepts. Initially, two groups received either isolated-elements (intermediate sub-calculation steps with fewer interacting elements had to be entered in separate spreadsheet cells before they were combined in a single cell) or interacting-elements instructions (the whole formula consisting of several sub-calculations had to be entered within one spreadsheet cell). This phase was followed by fully interacting elements instruction identical for both groups. The study demonstrated that for low-knowledge learners, using the initial isolated-elements technique was more effective than the fully interacting elements approach, while for more knowledgeable learners, there was no difference between the two methods.

It was suggested that the initially reduced task complexity by replacing the whole, fully interactive task by a number of less complex isolated components reduced intrinsic load at the beginning and allowed novice learners to acquire some partial schemas that eased working memory limitations during the following phase of instruction. As for the more knowledgeable learners, they already had similar schemas for handling higher levels of intrinsic load from the beginning and did not need the above technique. Blayney, Kalyuga, and Sweller (2014) demonstrated that task complexity interacted with both levels of element isolation and learner levels of expertise: expertise and complexity have countervailing effects.

Enhancing Germane Resources (Imagination Effect)

In order to increase working memory resources actually allocated by the learner to dealing with intrinsic cognitive load (i.e. to increase germane resources), students could be asked to imagine the procedural steps involved in a specific e-skill rather than continue to study the description of such steps. For example, Cooper, Tindall-Ford, Chandler, and Sweller (2001) applied this idea to the instruction on how to use a spreadsheet application. After studying a set of diagrams on a computer screen with embedded textual explanations of sequential steps, students were directed to turn away from the screen and imagine the steps of the procedure. The study showed that imagining a previously studied procedure was more effective than studying again the same procedure (an imagination effect), but only for relatively more knowledgeable learners: the technique was not effective for novices.

It was suggested that imagining a procedure required its processing in working memory. The available relevant knowledge structures allowed the more experienced learners to process large amounts of familiar information in working memory, and the imagination procedure directed their cognitive resources to the essential interacting elements of information. On the other hand, since working memory is very limited for novice learners, imagining a novel procedure might generate an excessive cognitive load for these learners. Studying the description of the procedure could better assist these learners in initial knowledge construction. In line with this assumption, Ginns, Chandler, and Sweller (2003) demonstrated that university students learned new for them HTML code more effectively by repeatedly studying worked examples of the corresponding procedures rather than imagining these procedures.

Conclusion

Many instructional materials and procedures used in teaching and learning e-skills could cause learner cognitive (working memory) overload. The paper provided examples of instructional methods developed within a cognitive load framework for reducing extraneous cognitive load, managing essential intrinsic cognitive load, and appropriately focusing working memory resources (enhancing germane resources) while teaching e-skills related to learning new computer software from manuals or learning how to use spreadsheets. These methods could possibly be effectively used in learning and instructing many other types of e-skills, however, research studies in their applicability in various specific areas of e-learning still need to be conducted in the future.

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Biography

Slava Kalyuga is Professor of Educational Psychology at the School of Education, the University of New South Wales, Australia where he received a Ph.D. and has worked since 1995. His research interests are in cognitive processes in learning, cognitive load theory, and evidence-based instructional design principles. His specific contributions include detailed experimental studies of the role of learner prior knowledge in learning (expertise reversal effect); the redundancy effect in multimedia learning; the development of rapid online diagnostic assessment methods; and studies of the effectiveness of different adaptive procedures for tailoring instruction to levels of learner expertise. He is the author of three books and over 90 research articles and book chapters in this area of research.