Effects of learner prior knowledge and working memory limitations on multimedia learning

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Abstract

This paper reviews recent applications of cognitive load theory to the design of interactive multimedia learning. Research on expert-novice differences has indicated that the learner prior knowledge base is the most important factor that influences learning. On the other hand, processing limitations of working memory significantly affect learning processes. An important consequence of these two features of human cognitive architecture is that multimedia presentations that are effective for low-knowledge learners can lose their effectiveness for more knowledgeable learners and vice versa (expertise reversal effect). Therefore, it is necessary to dynamically adjust instructional presentations as learners acquire more knowledge in a domain. The paper focuses on empirical findings associated with these implications for multimedia and hypermedia learning environments.

Keywords: Multimedia learning, cognitive load, prior knowledge, dynamic presentations

1. Human cognitive architecture

The two major components of our cognitive architecture that are critical to learning are long-term memory and working memory (for a comprehensive overview, see Sweller et al., 2011). Research in cognitive science starting from the pioneering studies by de Groot (1965) and Chase and Simon (1973) in chess expertise clearly demonstrated the critical role of the knowledge base in long-term memory in human cognition, including learning (e.g., Bransford,
Working memory is associated with conscious processing of information within the focus of attention. Its processing capacity and duration are severely limited when dealing with novel information (Baddeley, 1986; Cowan, 2001; Miller, 1956). In most models of working memory, it has two partially independent channels for processing visual and auditory information. Accordingly, the capacity of each of these channels is limited to only several units of information at a time.

The importance of the learner organized knowledge base 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 and Kintsch, 1995). Experts and more experienced learners rely on this mechanism in managing their cognitive load. Another critical mechanism is automating basic procedures to the point at which they do not require any conscious processing in working memory. Therefore, considering levels of learner expertise is critical for selecting optimal instructional designs for multimedia learning environments.

2. Expertise reversal effect

The expertise reversal effect relates to the interactions between the effectiveness of different instructional designs and levels of learner prior knowledge. If novice learners have to simultaneously process many new elements of information in working memory, the corresponding instructional design may result in a potential cognitive overload. To reduce this load, various design techniques have been suggested in cognitive load theory (e.g., eliminating split attention by closely integrating different parts of presentations, using several different modalities for presenting different components of instruction, or providing additional detailed instructional guidance).

However, if such instructional techniques are used with more experienced learners who already have an adequate relevant knowledge base, these learners may be forced to unnecessarily co-refer and reconcile the corresponding components of their knowledge base and the additionally provided information. These processes may distract these learners from fluently executing already learned procedures and taking the advantage of their knowledge base. More importantly, such processes may impose additional cognitive load that would reduce working memory resources available for further learning (e.g., making generalizations or refining and strengthening available knowledge structures). This mechanism has been suggested to explain the effect (see Kalyuga, 2007; Kalyuga and Renkl, 2010, Sweller et al, 2011, for recent overviews).

Two types of instructional conditions may cause unnecessary cognitive load resulting in an expertise reversal effect. If limited guidance (designed for more experienced learners) is provided to novice learners, it may force them into applying search-based cognitive processes resulting in extraneous cognitive load. Alternatively, the available knowledge base of more experienced learners may overlap with providing instructional guidance that has been designed for novices. In this case, relating and cross-referencing the overlapping internal and external representations of the same information may impose an additional extraneous load. Thus, for more knowledgeable learners, the provision of the same guidance as for novices may become redundant and hinder their performance relative to other similar experienced learners who have not been presented with such detailed instructions.

The major instructional design implication of this effect is the need to dynamically tailor specific instructional techniques and presentation formats to changing levels of learner expertise. The following sections review the available empirical findings associated with this effect in different interactive multimedia and hypermedia learning environments.

3. Expertise reversal in interactive multimedia learning

An advantage of using pictorial representations with (or instead of) verbal representations is their capability to present information in a more compact and cognitively efficient way when much of the needed information could be accessed at a single location without search (Larkin & Simon, 1987). Visual representations may therefore reduce cognitive load imposed by intrinsically complex materials. In interactive learning environments, dynamic visualizations are commonly implemented as instructional simulations and animations. Even though their use in
education (especially in science education) has increased significantly, they have not yet produced strong evidence of improved students’ learning outcomes (e.g., Tversky, Morrison, & Betrancourt, 2002). From a cognitive load perspective, dynamic visualizations may not always be consistent with processing limitations of our cognitive system (Plass, Homer, & Hayward, 2009).

3.1. Instructional animations

Animations could be cognitively demanding for learners due to their high levels of transitivity. Novice learners could benefit more from studying a set of equivalent static diagrams. On the other hand, more knowledgeable learners can handle the transitivity and may benefit from animations. For example, while learners with higher levels of prior knowledge showed better results after studying animated procedural examples in transforming graphical representations of linear and quadratic functions in mathematics, less knowledgeable learners performed significantly better after studying sets of static representations demonstrating main steps of the transformations on a single screen (Kalyuga, 2008).

Using animated and static representations of the relation of time to the Earth’s rotation, Schnotz and Rasch (2005) demonstrated that relatively low-experienced students learned more from static representations, while there were no differences for high-experience students. They also compared simple animations with interactive animations that allowed students to manipulate parameters. Results indicated that higher knowledge students learned more from interactive animations, while low-knowledge learners benefitted more from simple simulations.

3.2. Instructional simulations

Similar to animations, failures of some instructional simulations to demonstrate clear instructional advantages could be attributed to high levels of working memory load. Representational formats for the input parameters and levels of instructional guidance could be important factors that may differentially influence effectiveness of simulations for learners with various levels of prior knowledge in a task domain. Complementing traditional symbolic (e.g., verbal and numerical) representational formats for input parameters used in instructional simulations with iconic (pictorial) versions may enhance instructional effectiveness of simulations, especially for novice learners (Lee, Plass, & Homer, 2006).

Iconic representations contain concrete graphics to represent the various elements (e.g. flames to represent temperature, weights to represent pressure). In another dimension, traditional exploratory-based simulations could be complemented by worked-out versions of simulations as a form of incorporating components of instructional guidance into simulated learning environments. There has been empirical data obtained from studies that compared different formats of simulations for learning gas laws in high-school chemistry to support these assumptions (Homer & Plass, 2010; Kalyuga & Plass, 2007; Lee et al., 2006). The iconic representations eliminated or reduced resources needed for interpreting and storing meanings of symbolic information in working memory. The added iconic representations represent information that the learners would have to hold in their working memory.

However, Lee et al. (2006) demonstrated that while novice learners benefited from the added iconic representations, more experienced learners learned better from symbolic only representations. Iconic representations could be redundant for these learners and interfere with learning. Similar results were obtained by Homer and Plass (2010) in web-based simulations of the Kinetic Theory of Gas.

3.3. Instructional hypermedia

Unstructured web-based hypertext and hypermedia presentations can potentially impose high levels of cognitive load on low prior knowledge learners who may need to devote most of their cognitive capacity to searching for relevant elements of information. These resources would not be available for productive construction of appropriate knowledge structures thus inhibiting meaningful learning. These learners may learn better from more structured
representations or interactive presentations with restricted levels of interactivity (Kashihara, Kinshuk, Oppermann, Rashev, & Simm, 2000; Shapiro, 1999; Shin, Schallert, & Savenye, 1994).

For example, Kashihara et al. (2000) suggested the Exploration Space Control (ESC) methodology that intentionally limited the exploration space and this reduced learner search process. The extent of the exploration space was controlled according to the complexity of the task and the learners’ levels of understanding and prior experience by restricting exploration tools available to learners, tailoring the presented information, or recommending only some of the available choices. Shapiro (1999) demonstrated that interactive overviews that organized and structured hypermedia-based materials were more beneficial for novices than for more knowledgeable learners who had to process unnecessary sources of information.

Well-structured hypertext-based concept maps may demonstrate the hierarchy of relations between concepts, while unstructured maps may show only the network of relations without an explicit hierarchy. Amadieu, van Gog, Paas, Tricot, and Marine (2009) demonstrated that low prior knowledge students learned more conceptual knowledge in biology from structured concept maps, while there was no difference for high prior knowledge learners. All the participants in that study indicated less cognitive load when learning about the structured maps. Low prior knowledge learners demonstrated better recall of the material presented in the hierarchical structure format, while high prior knowledge learners showed better recall after studying the unstructured maps (Amadieu, Tricot, & Marine, 2009).

4. Tailoring multimedia learning to levels of learner expertise

According to the expertise reversal effect, multimedia presentation formats need to be tailored to levels of learner expertise. An important condition for designing adaptive presentations is the availability of diagnostic tools that can evaluate levels of learner expertise rapidly and in real time. A possible approach to such rapid assessment of expertise is based on observing how learners start solving (e.g. performing their first step towards a solution) briefly presented problems (the first-step diagnostic method; Kalyuga & Sweller, 2004). More knowledgeable learners would usually immediately switch to intermediate and more advanced steps, while less knowledgeable learners may only perform very first immediate steps or randomly search for a solution step. The rapid diagnostic methods were used in adaptive tutorials in algebra (Kalyuga & Sweller, 2004; 2005) and physics (Kalyuga, 2006).

An alternative to the system-controlled tailoring of presentation formats to levels of learner expertise is a learner-controlled approach according to which learners themselves select the formats they believe are appropriate at their current level of understanding. However, there is no sufficient empirical evidence that consistently supports the effectiveness of learner control in selecting optimal presentation formats (Chung & Reigeluth, 1992; Niemec, Sikorski, & Walberg, 1996). Since novice learners could be overloaded by the selection process itself, the learner-controlled approach may likely be effective for relatively more knowledgeable learners, thus leading to a possible expertise reversal effect in relation to the degree of learner control. Bell and Kozlowski (2002) suggested an adaptive guidance approach based on monitoring learner's progress and providing them with tailored guidance in selecting appropriate learning tasks.

5. Conclusion

The design of effective dynamic multimedia presentations needs to take into account processing limitations of human cognitive architecture. High levels of working memory load may inhibit learning, and levels of learner prior knowledge should be considered as a critical factor influencing learning outcomes. As learner experience in a domain increases, working memory limitations could become less important because relevant knowledge structures may already be available in long-term memory. As a result, presentation formats that are effective for novices may inhibit learning for more knowledgeable learners. Their knowledge structures need to be integrated with presented information that is redundant for these learners, thus causing an unnecessary additional cognitive load. This paper reviewed empirical findings associated with the expertise reversal effect in dynamic multimedia presentations. The interactions between different multimedia formats and levels of learner expertise have been found with a wide
variety of contexts and participants. The main instructional implication of this effect is the need to adapt instruction to levels of learner expertise to optimize cognitive load. Adaptive multimedia formats may enhance learning by providing personalized interactions and dynamic visualizations of instructional information.

References


