How may multimedia and hypertext documents support deep processing for learning?

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Abstract:

Digital documents as multimedia and hypertext documents provides for learning multiple information formats as well as multiple tasks (e.g. reading, exploration, interactions with information). These features could foster deep processing of material by promoting relational processes between the relevant parts of information. Such processes are expected to support the construction of meanings. Nevertheless, because the cognitive system's capacities are limited, relational processing could be difficult to run. In this paper, we examined three sets of research about learning with (a) multiple representations, (b) animations and (c) hypertexts. The conclusions confirmed that these digital documents could support deep processing by requiring relational processing, but only under some circumstances (i.e. learners with high cognitive abilities and guidance principles).

Keywords: animations, cognitive load, hypertexts, learning, multimedia, relational processes.

1. Introduction

Multimedia can be defined as the presentation of material using both verbal (printed or spoken text) and pictorial forms (e.g., graphs, pictures, maps, animations, videos, etc.) (Mayer, 2001). Within the educational world, there is a widespread adoption of multimedia materials. Multimedia provides access to a broad variety of representations and instructional materials. A lot of research on multimedia instructional design has been conducted over the past 20 years and still provokes vivid interest as evidenced by recent special issues (e.g., issue on motivation and emotion in multimedia, Mayer, 2014a; issue on eye tracking as a tool to study and enhance multimedia learning, van Gog & Scheiter, 2010). In this paper, we only consider multimedia designed to foster learning, that is to say, multimedia that provides information involved in the subject matter to be learnt and not decorative materials. Moreover, only learning relying on understanding is considered in this paper, excluding other types of learning, such as procedural or imitation-based learning.

Multimedia instructions are spreading thanks to technological development and offer new instructional perspectives by providing access to multiple representations, dynamic information and large information databases. Clark and Feldon (2005) pointed out beliefs about multimedia instructions. For instance, learning is better with multimedia than with other instructional media because it fosters engagement, motivation and allows discovery learning, or multiplying information formats including dynamic and interactive aspects prompts learners to pay attention to information and to deeply process the learning material. These authors warn us about these beliefs concerning multimedia learning and stress for instance that discovery learning can be very challenging for learners. Multiplying sources of information thanks to multimedia does not seem to be a sufficient condition to trigger deep learning. Sandberg and Barnard (1997) expected that an enriched environment made of different resources would lead the students to actively construct knowledge, but their results disproved an effect of the use of different sources of information on deep learning.

To understand multimedia learning, the cognitive processes have to be examined. Multimedia learning involves selection of relevant material, organization of contents into a coherent representation, and integration of this representation into knowledge (Mayer, 2014b). This paper focuses on the construction of meanings from multimedia and addresses the following question: can multimedia support deep processing of instructional material? It attempts to understand the extent to which processes involved in the construction of meaning from multimedia documents concern deep learning.

Constructing meaning from contents requires selective and relational processes that involve background knowledge. In the model of generative reading comprehension developed by Wittrock (1990), the construction of meaning requires building relations among parts of the contents and between the contents and the learner's background knowledge. According to this model, "… to learn with understanding a learner must actively construct meaning" (p. 349). Wittrock distinguished different ways to stimulate generation in order to construct meaning: (a) building relations among concepts presented in instruction (e.g. composing headings, writing summaries, drawing graphs) and (b) elaborating relations between instruction and prior knowledge (e.g. proposing analogues, drawing pictures or inferences). These selection and relational processes may be considered as deep processing. However, Dinsmore and Alexander (2012) showed that deep processing is not a stable construct. In our perspective and in line with Kester, Kirschner and Corbalan (2007), deep processing refers to a semantic analysis as opposed to a perceptual/physical analysis (e.g. Craik & Lockhart 1972; Osorio, Ballesteros, Fay & Pouthas, 2009) and to the learner's intention to understand the meaning, to build relations between the content to be learnt and prior knowledge (Sins, van Joolingen, Savelsbergh, & van Hout-Wolters, 2008).

As multimedia instructions provide varied sources of information and facilitate access to extended information, it can be expected that they will trigger exploration and relational processing and thereby support deep learning. Yet, as shown by Sandberg and Barnard (1997), providing multiple multimedia resources is not a sufficient condition to promote deep processing. As stated by Cognitive Load Theory (Sweller, Ayres & Kalyuga, 2011; Sweller, van Merriënboer & Paas, 1998), instructional design has to facilitate relevant processes for learning (i.e. germane cognitive load) and to limit processes that do not contribute to learning and that overwhelm learners' working memory (i.e. extraneous cognitive load). As it contributes directly to the construction of meaning from multimedia instructions, relational processing can be considered as belonging to the germane cognitive load. Actually, instructional designs may be either considered as bad if they make relational processing difficult to run (Seufert, 2003) or good if they promote it as a desirable difficulty. Desirable difficulties are "manipulations that appear to introduce difficulties and slow the rate of acquisition [but that] can enhance post-instruction recall and transfer" (Bjork, 2013, p. 243).

In this paper our goal was (a) to examine the relational processes involved in multimedia and hypertext learning that contribute to the construction of meaning, (b) to determine to what extent these processes are difficult to run and (c) how they could be guided if necessary. We focused on three main sets of research within the digital learning area: multimedia and multiple representations, animations and hypertexts. The novelty of the present paper is that it examines these different presentation formats through the same lens. The research under consideration in this paper belongs to the psychology and education area and is mostly recent. Because the number of studies on multimedia learning is too extensive to expand on here, this paper does not aim to draw an exhaustive picture of the literature. The selection of papers was based on two main criteria: (a) relevance to the questions examined in this paper (e.g. papers focusing on underlying cognitive processes involved in comprehension from multimedia, animations and hypertexts), and (b) recency of the papers. Due to the paper's ambition to cover different types of digital documents under a single approach, this literature review does not provide a systematic account of all the cognitive processes underlying comprehension with digital documents, or of the moderator factors that could impact the comprehension processes.

2. Learning from multiple representations: integration between different formats

Because multimedia conveys different representations of learning material, learners have to construct meaning from these different representations. Among the effects of the multiple representations on learning, the multimedia effect has been extensively documented: students learn better from text and pictures than from text alone (e.g., Mayer, 2009). While this effect is not systematic and depends on variables, such as the content to be learned, the learner's background knowledge level, his/her learning ability or spatial skills (Fletcher & Tobias, 2005), it remains a robust effect that is worth being explained. Specific models have been developed to explain the effects of multiple representations on learning (Mayer, 2001; Naranayan & Hegarty, 1998; Schnotz, 2001). We first review the main explanations of the multimedia advantage to assess what role relational processing plays and we report some empirical evidence of this role. We also present ways to support relational processing in multiple representations.

2.1. Cognitive processes underlying the multimedia effect

Three main possible explanations may account for the benefits associated to the presentation of pictures (see Glenberg & Langston, 1992, for a longer list of possible accounts). A first possible explanation borrows from the dual code theory (Paivio, 1986) and has been qualified as the "*outcome oriented view*" by Van Genuchten, Scheiter, and Schüler (2012): pictures and text give rise to distinct representations which serve as different access points to the same information in long-term memory. Consequently the information is more probably available and accessible when compared to a text only condition. According to this hypothesis, the multimedia effect relies on improved access to information in long-term memory due to dual coding of information and has nothing to do with relational processing.

A second explanation is that, thanks to their analogical nature, pictures convey visuo-spatial information more directly than textual information, such that some cognitive demands associated to information processing of the content to be learnt are reduced. For instance, maintaining pictorial information in working memory would be less costly (e.g. Eitel, Scheiter, Schüler, Nyström, & Holmqvist, 2013) and drawing inferences from pictures would be easier than from text (Van Genuchten, Scheiter, & Schüler, 2012) because it would rely on perception rather than on semantic interpretation (Larkin & Simon, 1987). This led Eitel et al. (2013) to the scaffolding hypothesis: pictures provide relatively direct access to mental model construction, so that presenting a picture before a text facilitates its processing. This explanation does not place a particular emphasis on relational processing.

A third explanation of the multimedia effect is that the presence of pictures stimulates the need for integration between pictorial and textual information (i.e. building referential connections between both types of representations) and this integrative process is a basis for inference generation (Glenberg & Langston, 1992; Jamet & Erhel, 2006) and meaningful learning. According to Jamet (2008), a major point of agreement between the different models of text and picture comprehension (Hegarty, Narayanan & Freitas, 2002; Mayer, 1997; Schnotz, 2002) is the importance of this integrative process. In this sense, the adjunction of pictures to texts could be considered as a desirable difficulty: pictures would help because they trigger integrative processes that are useful for learning. This explanation stresses the importance of relational and generative processes in the multimedia advantage.

2.2. Relational processes between information representations

Empirical studies lean toward the integrative hypothesis. For instance, Gyselinck and Tardieu (1999) showed a positive effect of illustration on inference generation when learning from expository texts. They specifically demonstrated that to be efficient, pictures must be presented simultaneously with the text, to allow readers to navigate between the pictorial and textual information. More recently, Mason, Tornatora and Pluchino (2013) showed that when asked to read an illustrated text, the more fourth-graders reveal integrative processing between texts and pictures (e.g., number of times eye fixation is moved from text to picture and vice versa), the better they learn. Johnson & Mayer (2012) obtained converging results. More extensively, similar results on integration processes of multiple representations were obtained by O'Keefe, Letourneau, Homer, Schwartz and Plass (2014). They found that a greater frequency of transitions between representations of a multimedia support (picture and graph) predicted better transfer scores.

Relational processing between multiple representations can be promoted by the instructional design. For instance, Bodemer, Plötzner, Feuerlein and Spada (2004) observed that learners who had to actively integrate different representations (i.e. learners had to relate textual and algebraic components to visualization components by drag and drop) outperformed learners who received a pre-integrated representation.

2.3. Guiding learners towards relational processes

As discussed above, active processes of integration between different representations predict better deep knowledge classically assessed by transfer tests. However, instructional designs should offer guiding tools that facilitate these active processes leading learners to focus on the interrelations between different representations. A recent study conducted by Jamet (2014) confirmed a guidance effect of cueing in a multimedia document including static diagrams and spoken explanations. Learners paid more attention (total fixation times) to the relevant information when cueing was provided. However, while cueing entailed higher scores to completion and retention tasks, it did not improve the transfer score. As hypothesized by the author, the cueing used in this experiment highlighted isolated items, thereby it promoted selection of relevant items rather than relational processes of items that could help to construct a more coherent and interconnected mental model.

Van der Meij and de Jong (2011) pointed out that learners often encounter difficulties finding and interpreting the relations between different representations. In their study, they investigated the effect of self-explanations that are expected to promote deep processing. They showed that directive self-explanation prompts to relate and translate between representations, gave higher learning performance than providing general self-explanation prompts that do not point the relations between the representations. In sum, to promote deep processing and a better comprehension, directive self-explanations guiding generation processes on the relations between representations or piece of information should be preferred to general self-explanations.

2.4. Conclusion

Active learning seems to be partly responsible for the multimedia effect by promoting relational processes between different information formats or representations, but to the extent that the multimedia design is in accordance with this cognitive requirement, otherwise learners can experience an extrinsic cognitive overload that is detrimental to learning.

In sum, relational processing between representations should be supported by an appropriate design respecting principles such as the spatial contiguity principle (textual information should be integrated into pictures or at least, should be presented very close to the pictorial information, e.g. Sweller, 1999). If the spatial contiguity is not respected, the integration between textual and pictorial information cannot take place and a split-attention effect may occur (for a review, see Ayres & Sweller, 2005), such that the need for integration becomes an undesirable difficulty.

3. Learning from animations: organizing dynamic information

"*Animation refers to a simulated motion picture depicting movement of drawn (or simulated) objects. The main features of this definition are as follows: (1) picture – an animation is a kind of pictorial representation; (2) motion – an animation depicts apparent movement; and (3) simulated – an animation consists of objects that are artificially created through drawing or some other simulation method*" (Mayer & Moreno, 2002, p.88). Animations are useful when learning materials concern dynamic information (Bétrancourt & Tversky, 2000). Inclusion of animations in educational approaches may have a long-term effect on learning as compared to traditional approaches (Urquiza-Fuentes & Velázquez-Iturbide, 2013). However, our comprehension of what in animations is really effective for learning still requires investigations. To this end, Ploetzner and Lowe (2012) extracted various dimensions characterizing the animations and that should be considered (e.g. the type of representations employed in terms of realism, the representation of time, the segmentation of the animation, user control). Furthermore, a meta-analysis conducted in 2007 on 26 studies (Höffler & Leutner, 2007) provided conclusions in favor of animations and also indicated that moderating variables weight the efficiency of animations (e.g., procedural-motor knowledge rather than declarative or problem solving knowledge).

3.1. Animations as a "cognitive prosthesis" or as an undesirable difficulty?

Animations are expected to ease the construction of a mental model of a dynamic system by displaying dynamic information that limits inferential activities for learners. Animation can compensate learners' insufficient aptitude or skills to simulate motions or dynamic processes, like spatial abilities (Hegarty, 2005). Höffler and Leutner (2011) as well as Münzer, Seufert and Brünken (2009) provided evidence of a compensatory effect of animation (i.e., animations compensate for a learner's spatial abilities deficit, while with static pictures, spatial abilities enhance learning). Animations play the role of a cognitive prosthesis, limiting inference processes of spatial and dynamic information, while static pictures impose active processing of motions supported by spatial abilities.

However, animations do not only support processing of spatial and dynamic information, they impose challenging processes as well (i.e., selection and organization processes of the units making up animations). As discussed by Tversky (2011), animations appear to conform to the Congruity Principle because they display change in time to show change in time, but learners need step-by-step presentations to construct well-organized mental representations. Besides, due to their complexity and speed, they can violate the apprehension principle. Regarding to the Animation Processing Model (Lowe & Boucheix, 2011), learning from animations implies five broad phases involving bottom-up and top-down processes. During phase 1, the dynamic information is parsed into event units, which have to be selected by learners. In phase 2, the spatially selected and temporally adjacent event units are combined to form dynamic micro-chunks. In phase 3, the dynamic micro-chunks are interconnected to compose a superordinate organizing structure (e.g., domain-general causal chains). Phases 4 and 5 concern top-down processing mobilizing background knowledge. Selecting units and organizing them into a mental representation may overwhelm an individual's working memory and hamper learning processes (de Koning, Tabbers, Rikers, & Paas, 2009). Besides, animations might entail difficulties for learners, particularly by presenting transient information (Leahy & Sweller, 2011; Singh, Marcus & Ayres, 2012; Wong, Leahy, Marcus & Sweller, 2012). Learners may encounter difficulties to maintain information in memory (temporal limit of working memory) and some of the animation steps are no longer accessible for learners after they view them. A consequence for designing efficient animations is the need to limit the difficulty (i.e. extraneous cognitive load) for learners to conduct such processes.

A limit of animation relates to the attentional processing engaged in visualization of the dynamic information. Perceptually salient information, such as seductive details or irrelevant movements, may catch the learners' attention at the expense of more conceptual relevant aspects (Lowe, 1999, 2003). To limit attentional demands, the authors studied the attention-guiding principle (Ayres & Paas, 2007; Bétrancourt, 2005), consisting in directing learners' attention to specific parts of the learning material. To decrease the attentional requirements, the attention-guiding principle was designed to cue relevant information (e.g., signalling relevant information at a step of an animation). Evidence points to positive effects of cueing on learning (e.g., de Koning, Tabbers, Rikers, & Paas, 2007). Analyses of on-line processes corroborated an impact of cueing on selection processes directing learners' attention (Boucheix, Lowe, Putri, & Groff, 2013).

3.2. Limitation of extraneous cognitive load and guiding relational processing in animations

Selecting the relevant information in animations might be difficult for learners. To understand a process, learners should select the macro-information that structures the processes. However, as shown by Meyer, Rasch and Schnotz (2010), although macro-event information is more easily perceived when the presentation speed of animations is high, learners tend to focus on micro-events, even at high speed. Providing user-control (pace, navigation backward-forward, manipulating objects) can help learners to adapt the flow of information to their needs. For instance, Höffler and Schwartz (2011) showed that self-pacing (i.e., buttons to start playing the animation, to pause and to fast-forward or rewind the presentation) enhanced learning with animations. Chien and Chang (2011) showed that giving learners the opportunity to physically manipulate a virtual measuring mechanism (i.e., Abney level) in an animation decreased mental effort and increased learning performance in comparison to a conventional animation (learners could control only the pace) and to a static condition (pictures instead of a dynamic presentation). Boucheix and Schneider (2009) showed that user-controlled presentations were helpful for learners, but only for low-ability learners (spatial abilities and mechanical reasoning). Their results mean that the user-control of animations may release resources into working memory, reducing the amount of ineffective processes for learning and allowing learning regulation for low-ability learners. However, the literature analysis about animations conducted by Ploetzner and Lowe (2012) indicated that the positive effect of user control is not systematic.

Another principle that can help learners to select the macro-information is the segmentation principle. A recent study conducted by Spanjers, van Gog, Wouters and van Merriënboer (2012) highlighted the positive effect of information segmentation (i.e., animation with pauses in contrast to a continuous stream of information) on learning with animations. Insertion of pauses between segments allows learners to perform the necessary cognitive processes and segmenting animations would act as temporal cueing, signaling the meaningful pieces of information stressing the structure of the process. Arguel and Jamet (2009) also demonstrated a beneficial effect of segmentation by adding pictures to animations; the pictures supported processing of animations by pointing out the crucial steps of the process.

3.3. Guiding learners to relational processes

Beyond the attentional guidance principle, Kombartzky, Ploetzner, Schlag and Metz (2010) clearly showed the need to guide learners in their learning strategies with animations. Mason, Lowe and Tornatora (2013) observed that self-generated drawing (i.e., production of drawings to represent what learners observed in the Newton’s Cradle animation) enhanced learning from animation in comparison with a copied-drawing (i.e., learners copy a given step of the Newton’s Cradle) and a no drawing condition. Learners are engaged in extraction processes of relevant information and structuration processes, irrespective of its salience, respecting Animation Processing Model (Lowe & Boucheix, 2011).

De Koning, Tabbers, Rikers and Paas (2010) compared two instructional animations. One of the animations implied learner-generated self-explanations (learners explained aloud the functioning of the cardiovascular system during the animation) while the other one provided instructional explanations via auditory narration. Their results indicated that external explanations provided to learners increased the inference scores (questions about functioning relations between elements) compared to generation of self-explanations. The number of inferences generated by learners in the self-explanation condition was quite low. This highlights the difficulty for learners to generate relational inferences from an animation. Animations require visual attention to select relevant information.

3.3. Conclusion

Animations may support the building in memory of dynamic processes resulting in a lower cognitive load in contrast to static pictures. Animations act as a “cognitive prosthesis”, reducing the cognitive cost of mental simulation of a dynamic system. Mentally reconstructing a dynamic process from static picture is demanding and requires cognitive skills like spatial abilities. Nevertheless, animations impose attentional and memory requirements. Animations require perceptual and cognitive resources to process their spatial and temporal aspects (Bétrancourt, 2005).

Extracting relevant elements and constructing functional relations between the elements contributes to the germane cognitive load on the condition that guidance is provided to reduce extraneous cognitive load. However, as demonstrated by De Koning et al. (2010), these comprehension processes have to be supported by narration or signaling rather than by self-explanations. Instructional animations have to help learners establish relations between elements and limit the need of running elaborative inferences based on background knowledge.

4. Learning from hypertexts: establishing semantic connections

Hypertexts are used for searching information, communicating, comprehending and learning. A specificity of hypertexts relies on non-linear access to information. Readers navigate within an information space according to their needs and goals. Such an interaction with documents is expected to facilitate access to information by contrast with more linear documents like paper documents. Moreover, non-linear access to information is adapted for comprehension of multiple documents from different sources because it provides a fast access to different information sources that can be compared (Britt & Rouet, 2012). However, non-linear reading in hypertexts may be demanding and imposes difficulties to learners as shown in the following section.

4.1. Navigation and coherence processing

Processing hypertext requires readers to run specific processes in order to efficiently navigate (e.g., selecting links or remembering their pathway), to fill in information gaps and to self-regulate their learning (DeStefano & LeFevre, 2007; Shapiro & Niederhauser, 2004). In addition navigation-related processes, learning from hypertexts requires processes for integration of information from different locations by establishing semantic relationships between information nodes (i.e., assembling pieces of information in memory in a cohesive mental model) and maintaining coherence of reading pathways over navigation (Madrid, Van Oostendorp, & Puerta Melguizo, 2009; Salmerón, Cañas, Kintsch, & Fajardo, 2005). All those necessary processes may be challenging for learners. Only highly skilled readers are not or less affected by those challenging tasks (e.g., Amadieu, Tricot, & Mariné, 2011; Naumann, Richter, Flender, Christmann, & Groeben, 2007; Salmerón & García, 2011).

4.2. Relational processes supported by prior knowledge and graphical overviews

Nevertheless, studies conducted by Salmerón and colleagues (Salmerón, Kintsch, & Cañas, 2006; Salmerón et al., 2005) contributed to the hypothesis of active learning when high prior knowledge learners process hypertexts. However, it is necessary to conduct further studies to study active learning effects with hypertexts. Actually, much research has been conducted on guidance tools in hypertexts to reduce the cognitive costs involved in hypertext processing. For instance, one of the most extensively studied guidance tools is overview (e.g., concept maps), that conveys a spatial and/or semantic structure of a hypertext document (for a literature review, see Amadieu & Salmerón, 2014). An overview is an organizational framework supporting encoding, storing and retrieving text content in memory. Overviews of a hypertext's structure facilitate selection and organization of contents (Cuddihy & Spyridakis, 2012; Gurlitt & Renkl, 2009; Naumann et al., 2007; Salmerón & García, 2011). Overviews seem to be used more by readers to encode hypertext structure than embedded links (Vörös, Rouet, & Pléh, 2011).

Selective, relational processes, along with navigation, are facilitated by adjunction of overviews in hypertexts,. Overviews help learners to visit sections more relevant to their objectives (Puntambekar & Goldstein, 2007) and to construct more coherent pathways (Amadieu, Tricot, & Mariné, 2009). It is interesting to note that a recent study carried out by Bezdan, Kester and Kirschner (2013) stressed the benefit of nonlinear reading of a hypertext with overviews (i.e., concept maps in the study). The authors observed that restricted navigation with a navigation concept map (i.e., from one node to adjacent nodes) is detrimental for comprehension as compared to unrestricted navigation (i.e., readers can jump from any node to any other node). This result suggests that a trade-off must be found between the navigation freedom traditionally allowed by hypertexts and guidance provided by overviews to foster comprehension and learning.

4.3. Conclusion

Comprehension and learning from hypertexts requires relational processes between pieces of information consisting in establishing semantic connections between the information parts. If learners have a high level of domain background knowledge, they are able to cope with these semantic elaborations and can even benefit from coherence gaps imposed by hypertexts by triggering deep inferential activity. If not, learners have to be guided to run relational processes by overviews of a global semantic organization of the hypertext.

5. General discussion

The studies conducted on learning with digital material highlight that multimedia, animations and hypertexts can lead learners to deep comprehension of the material by requiring relational processes between the relevant information parts. Nevertheless, although the findings tend to confirm that the relational processes are crucial to construct a coherent mental model and to mobilize it for transfer tasks, they also pointed out that learners cannot systematically draw these types of processing. Such processes require either cognitive resource to be run, such as prior domain knowledge, or guidance to limit interfering processes and to drive learners' attention to the relational processing.

While text and picture formats or multiple representations can promote a better use of working memory resources under some circumstances, they may also be challenging by causing a split of attention between the information sources that hamper the relational processes between the different representations. As far as animations are concerned, they contribute to learning of dynamic information, but require an adapted design to guide content selection and organization processes. Finally, hypertexts convey nonlinear and free access to information that can promote inferential activity, but once again, this can also be cognitively challenging. Tools such as graphical overviews, which highlight the content structure, assist learners in navigating through information space and processing the relations between the information sections.

In sum, constructing meaning from digital documents can be facilitated by designs that both foster relational processes (i.e. germane cognitive load) between different formats, representations or parts of information, and assist these processes by reducing the cognitive cost imposed by processes ineffective for learning (i.e. extraneous cognitive load). In other words, in order to foster deep comprehension with digital documents, cognitive resources must be released to allow the relational processes. Deep processing should be promoted to the extent that the resources required to run the appropriate cognitive operations do not overload working memory. Leading learners to generate connections between the information parts themselves is a desirable difficulty *as long as the* learner responds to the challenge it triggers. For instance, if presenting a picture and a text requires learners to generate some inferences and if learners are equipped for this, one could say that presenting pictures is a desirable difficulty for learning. However, if the presentation format requires inference generation that learners cannot afford (due to weak cues or insufficient background knowledge), it becomes an undesirable difficulty. The learning paradox is that students with high prior knowledge, who have less need to learn, have more capacity to process information and therefore to learn. The more learning requires generative processes, the more demanding it is, the stronger the paradox is.

The issue of the level of generation, or desirable difficulty, imposed by digital documents is important to design effective instructional environments. A recent study conducted by Eitel, Kühl, Scheiter and Gerjets (2014) showed that disfluency (less legible text) was beneficial for learning in one experiment whereas it tended to be detrimental in the other three experiments. This result illustrates the need to conduct research examining the conditions under which multimedia instructions trigger deep effective processing rather than ineffective processes. Because learning that requires learners to generate is time-consuming, greater attention should be paid to factors that support learners’ engagement and efforts in such learning, such as self-beliefs and achievement goals. Actually, many factors (contextual factors, perceived contextual factors, student factors) influence the use of deep or shallow approaches to learning (for a review see Baeten, Kyndt, Struyven & Dochy, 2010).

Furthermore, more investigations with online measures (e.g. time on task, eye pathways) should extensively contribute to determining to what extent deep processing is engaged in learning with digital documents. Finally, because one feature of deep learning is to lead to long-term knowledge, delayed measurements of learning performance should be considered more closely in the studies. As shown by Scheiter, Schüler, Gerjets, Huk and Hesse (2014), multimedia and modality effect may impact immediate recall performance and vanish over time (delayed tests).

This paper only focused on a fraction of learning situations with digital documents. Further investigations on the effects of multimedia supports and the underlying cognitive processes should be continued. More research should strive to disentangle the processes involved in multimedia learning environments that are relevant (i.e., supporting deep integration in long-term memory) and irrelevant (e.g., interfering by overwhelming working memory) for learning. Besides, the types of learning tasks evolve with technology development, providing new tasks for learning. For instance, increasing numbers of students browse, explore, and view information on the Web. Rather than just studying a single text, learners can search for information about a topic to be learned. Electronic document search processes might contribute to learning.

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Acknowledgement

This paper was written in the framework of the research project CISH supported by ANR (National Research Agency) - JCJC SHS 2 – 2011.