Investigating multimedia effects on concept map building: impact on map quality, information processing and learning outcome.

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Abstract

Two experimental studies were carried out to investigate whether adding multimedia features in a concept mapping task would improve the quality of the map built by students and promote more effective learning with expository hypertexts. Ninety-Nine undergraduates built a concept map to learn about a topic (water cycle or nitrogen cycle) either with a text-based or with a multimedia presentation of concepts (*i.e.* concepts were presented as textual labels illustrated with relevant pictures). Multimedia presentation of concepts was expected to foster the construction of a more elaborate concept map, to increase information processing and to improve learning outcome. Results of the two experiments were consistent by showing that multimedia presentation led learners to spend more time building the concept map and to build more coherent maps (*i.e.* text-based inter-connected concepts). In addition, experiment 2 showed that the multimedia presentation of concepts in concept mapping could also foster deeper exploration of the hypertext. However, learning outcomes were not affected by the learning conditions

Keywords: concept mapping, multimedia effect, hypertext, information processing, navigation, learning

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Introduction

Over the last years, concept mapping has become an increasingly popular activity for online learning because it is usually expected to promote active learning. In hypertext environments, learners have to elaborate a coherent mental model that integrates information extracted from different nodes of information (*i.e.* different content pages) (DeStefano & LeFevre, 2007; Rouet & Britt, 2011). Hence, comprehension processes in an online document requires learners to assess information relevance, make decisions to navigate between content pages and make inferences to connect the pieces of information extracted to one's own mental model and prior knowledge (Salmerón, Baccino, Cañas, Madrid & Fajardo, 2009). Interruptions, decision-making to switch between pages and inference-making to connect information can cause cognitive overload, disorientation and hinder comprehension or learning (Bezdan, Kester, & Kirschner, 2013). Consequently, learners have to allocate resources to maintain coherence both at the semantic and navigation levels in order to elaborate a relevant mental representation of the hypertext content and follow a coherent navigational path. However, maintaining coherence can become increasingly difficult, especially for low knowledgeable learners (Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; Voros, Rouet, & Pléh, 2011; O'Donnell, Dansereau, & Hall, 2002). Graphic organizers, such as concept maps, can help learners cope with these challenges by supporting navigation and the elaboration of a more coherent mental representation of the hypertext's structure (Amadieu & Salmerón, 2014). Yet, constructing a concept map is not always beneficial and can even be detrimental for learners. Indeed, building a concept map is a complex task that can cause higher cognitive load and decrease learning outcome (Schroeder *et al.*, 2017; Stull, & Mayer, 2007). Hence, investigating the conditions facilitating concept mapping for learners is essential to design more effective instructional hypertexts.

In two studies, we investigated whether concept mapping could be supported by facilitating students' processing of the concepts thanks to a multimedia presentation of the concepts (*i.e.* textual and pictorial labels). Most prior works investigating the impact of multimedia features on concept mapping focused on the impact of the intrinsic multimedia characteristics of the concept map (*i.e.* building a representation of a learning material content with textual material and visual features such as arrows or visual signaling devices like color and arrows) (see for instance Vazquez-Cano, Lopez Meneses, Sanchez-Serrano, & Sarasola, 2015). However, the more complex multimedia features included in such studies were only embedded in the hypertext and not within the concept mapping software. Indeed, learners could have access to pictures in the hypertext document, but they were not included in the concept map. This limitation is addressed in a prior theoretical work by Alpert and Grueneberg (2001). The authors point out that current concept mapping softwares do not take advantages of the potential benefits of the multimedia features of digital documents. To the best of our knowledge, only one experimental study has clearly investigated whether adding multimedia elements to a concept mapping task could improve learning outcome for expository content (Morfidi, Mikropoulos, Rogdaki, 2017) (as compared to a concept mapping software that does not provide any extra multimedia features within the concept map itself). However, this study focused on concept map studying (and not concept map building) and did not examine the impact of a multimedia presentation of concepts on students' processing strategies. The present study will address this knowledge gap and investigate whether a multimedia presentation of concepts on the mapping software can improve the quality of the map built, foster more effective processing strategies and support learning outcome.

The following sections will discuss the impact of concept mapping on learning and will provide evidence for a potential multimedia effect on concept mapping. Next, we will present two studies in which we investigated how provided both pictures and text as concept labels can influence the construction of the concept map and learning outcome. Finally, the discussion section will synthesize and discuss the results observed.

Concept mapping: a complex but potentially beneficial activity to support learning that challenges learners

Concept mapping can require learners to build a map entirely (*i.e.* mapping-by-self, Colliot & Jamet, 2018a; Redford, Thiede, Wiley, & Griffin, 2012) or fill in a map with a partial framework (*i.e.* guided construction, Stull & Mayer, 2007). Theoretically, self-generated concept maps can offer several advantages. First, constructing a concept map allows the learner more flexibility to adapt the structure of the map to the organization of his own prior knowledge (Chang et al., 2001). Building a concept map also entails greater and deeper generative processing (as opposed to a text reading situation or studying an expert-provided concept map), such as deciding how to summarize the macro-structure of the learning content (Schroeder, Nesbit, Anguiano, & Adesope, 2017). Advantages and limitations of generating a concept map are summarized in Table 1 below. Advantages of concept mapping mainly rely on generative theories of comprehension (Wittrock, 1989) which postulate that allocating extra resources to relational processes can support better comprehension. In contrast, cognitive load theory (De Stefano, & Lefevre, 2007; Sweller, 1994) argues that concept mapping can represent an additional instructional design that can increase extraneous processing (*i.e.* processes that are not essential for learning) at the expense of germane processing and can thus overload working memory resources.

Table 1: Advantages and possible limitations of concept mapping.

Advantages of concept mapping	Limitations of concept mapping
- Encourages generative processing (*i.e.* meaningful selection of information and inference-making) (Schroeder et al., 2017). - Higher flexibility to adapts to learners' own knowledge structure	- Needs more training (unfamiliar task) - Requires maintaining active a great number of information in working memory in order to build a coherent concept map

- Highlights the hypertext's content structure - Can promote a better use of resources in working memory by providing learners with an external representation of the hypertext's structure that supports relational processes and coherent navigation (*i.e.* otherwise learners would have to allocate extra resources to elaborate a mental representation of the hypertext's structure and keep it active in working memory). - Improves metacomprehension (Redford et al., 2012)	- Learners (especially novices) may need help as there is no pre-determined processing order (Adesope & Nesbit, 2013) - Can cause extraneous cognitive load and hinder generative processing (Colliot & Jamet, 2018a and 2018b; Stull, & Mayer, 2007)

Despite its possible benefits, concept mapping is often moderately associated with an enhanced learning performance, as compared to studying with an already constructed concept map or content organizer, or to constructing texts (Colliot & Jamet, 2018a; Schroeder et al., 2017; Stull, & Mayer, 2007). For instance, Lechuga, Ortega-Tudela and Gomez-Ariza (2015) provided evidence that concept mapping can be so difficult that it does not present any advantage as compared to other learning tools such as repeated retrieval practice. Amadieu et al., (2015) also discussed how asking learners to elaborate connections between concepts in a hypertext can be quite difficult. Prior knowledge represents a major leverage for learners as it greatly contributes to the elaboration of a coherent mental representation of the learning content and can help learners cope with the cognitive costs of concept mapping (Amadieu et al., 2009; Dogusoy-Taylan & Cagiltay, 2014). Indeed, less knowledgeable learners may have more difficulties when constructing a concept map, particularly if the task provides no support (Nesbit & Adesope, 2006). Prior researches have also demonstrated that concept maps can help learners activate their prior knowledge and can later on facilitate the elaboration of connections between concepts and the integration of information (Gurlitt, & Renkl, 2008; Schroeder et al., 2017). All these findings emphasize the need for further research to enhance the benefits of concept mapping while supporting this activity (*i.e.* providing guidance or reducing its cognitive costs). One approach to reduce the possible limitations of concept mapping, especially for low prior knowledge learners, might be to provide a pre-determined reading sequence (*i.e.* sequential signaling), a pre-constructed structure, or feedbacks along the activity (Amadieu et al., 2015; Roessger et al., 2018; van Amelsvoort, van der Meij, Anjewierden, & van der Meij, 2013). However, some of these solutions can be demanding (require a teacher to participate for instance, Roessger et al., 2018), can lack flexibility (*i.e.* a pre-constructed map can require extra cognitive resources to be understood by the readers and does not evolve all along the task) or showed mixed results (Colliot & Jamet, 2018b).

Evidence for the interaction of multimedia presentation and concept mapping

On a theoretical plan, multimedia effect (Mayer, 2009) take roots in dual coding theory (Paivio, 1986) which states that multiple presentation formats increase the availability and accessibility of information in working memory. In addition, pictorial representations can also support inference-making by relying on perceptive processing (rather than cognitively demanding semantic ones) and by lowering the cognitive costs required to maintain information active in working memory (Larkin, & Simon, 1987). Hence, relevant pictures allow learners to elaborate a relevant mental model more rapidly and easily (Eitel, Scheiter, Schüler, Nyström, & Holmqvist, 2012) and can support learning performance (Lenzner, Schnotz, & 2013). The cognitive theory of multimedia learning (Mayer, 2009) and the integrative model of text and picture comprehension (Schnotz, 2002) explain the benefits of multimedia effect with regards to their impact on relational processes. Both models claim that pictures and texts give rise to different representations that are both coupled at a later stage in order to form a coherent global mental model, thanks to learners' prior knowledge, Adding pictures to a learning material requires learners an extra effort to integrate information coming from all formats and fosters a better integration of information (Mayer, 2005; Schnotz, 2005). In addition, pictures can provide semantic and spatial information very rapidly. Consequently, learners do not have to allocate extensive resources to process them and keep them active in working memory (Schnotz, 2002; Schüler, 2017). Finally, the mental representation elaborated from pictures can serve as a mental scaffold to support the elaboration of later representations that integrate information extracted from texts and from additional prior knowledge (Gyselink, Jamet, & Dubois, 2008). On a theoretical plan, adding multimedia elements to a concept mapping task seems to be a promising way to facilitate the elaboration of a concept map and improve learning outcome. However, a study by Morfidi, Mikropoulos, and Rogdaki (2018) showed that studying a concept map with multimedia features did not lead to different learning outcomes as compared to studying a text-based only concept map. It is to be noted that when investigating the impact of multimedia effect, prior research tended to use learning material of varying nature. Indeed, the pictures provided alongside textual expository material can either depict a more or less abstract concept (such as "*a lightning strike*"), or the relationships between several concepts (semantic or spatial ones) or processes (such as "*production of greenhouse gas*") (Serra, & Dunlowsky, 2010). Based on this review of literature, we argue that a multimedia presentation of concepts labels in a concept mapping task may facilitate:

(1) the identification and categorization of concepts (thanks to perceptual clues that help learners identify the different concepts and cluster them depending on their relative relevance, Ainsworth, 2006),

Perceptual clues could also provide guidance on how to start processing information, where to go next, and should thus facilitate the processing of the hypertext content pages (Pirnay-Dummer, & Ifenthaler, 2011; van Amelsvoort et al., 2013). In other words, these perceptual clues could play the role of signaling devices to help learners: identify the topic, understand the organization of the learning material (*i.e.* if a picture represents how a particular concept can relate to other concepts) and emphasize salient information (*i.e.* a picture can for instance help learners understand if the concept tackled is a process – *the emission of greenhouse gas* – or a particular concept – *the molecule carbon dioxide* –).

(2) the integration of information (by supporting relational processes that represent a key to improve the quality of the map built and its benefits of learning, (Roessger et al., 2018).

(3) the spatial distribution of the nodes of information on the concept map (*i.e.* concepts and links between them) as pictures should make more salient the spatial features of each concept (Schnotz, 2002).

Hypotheses of the studies

The present study will innovatively examine whether multimedia features in a concept mapping task can facilitate the elaboration of the concept map (*i.e.* promote deeper engagement in the map construction and improve the quality of the map built) and support students' learning outcome with an expository hypertext. To test this, two experiments (with two different learning topics) were designed in which participants had to build a concept map (either with concepts presented as simple text labels or as textual labels illustrated by a relevant picture) and learn as much as possible to answer a questionnaire assessing their comprehension (see Figure 1 for a schematic view of our hypotheses).

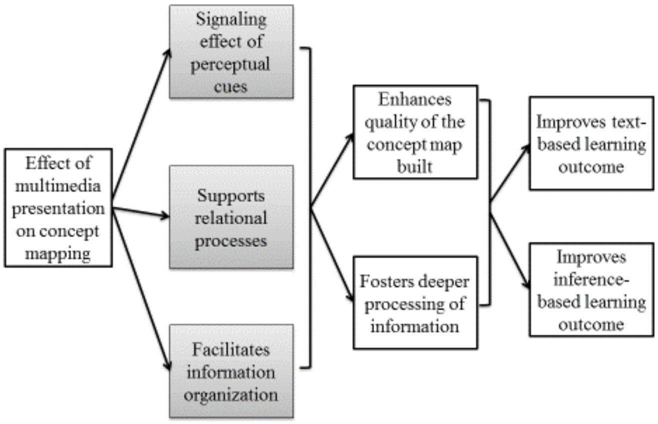

Figure 1: schematic overview of the expected theoretical impact of multimedia presentation on concept mapping.

It was hypothesized (H1) that pictorial and textual concept labels would support both hypertext exploration (*i.e.* enhance content pages processing) and map construction (as compared to the text only condition), and the quality of the built maps.

- Regarding content pages processing, we expected that multimedia features in the concept map (*i.e.* when concepts are presented in the concept map as text and pictures) should lead learners to visit a greater number of content pages (H1a) and to spend more time processing the content pages consulted (H1b).
- Regarding the concept map building, it was hypothesized that multimedia features should foster more engagement in the map construction. Consequently, it should increase the time spent building the map (H1c).
- Regarding the quality of the map, the multimedia presentation of concepts was expected to support higher-quality maps by helping learners in the relational and organizational processes. Therefore, it was hypothesized that the number of correct text-based and inference-based links between concepts should be higher in the multimedia presentation condition than in the text only condition (H1d).

Regarding learning outcomes, the expected benefits of multimedia presentation on the construction of the concept map should increase both text-based and inference-based learning outcomes (H2).

2. Experiment 1

2.1 Method

Design

This study was carried out in a laboratory setting, following a between-subjects design. The independent variable consisted in two different presentation formats of the concepts' labels on the concept mapping software. Specifically, half of the participants built their concept map with textual material only (*i.e.* concept labels consisted in plain text) whereas the other half had pictorial and textual material (*i.e.* concept labels consisted in plain text illustrated with a significant picture).

Prior knowledge and learning outcome tests

A multiple choice questionnaire (four possible answers including “I don’t Know”) was used to assess the amount of prior knowledge participants had about the topic. Eight questions assessed text-based knowledge (*i.e.* the answer would be explicitly written in the texts) and eight questions assessed inference-based knowledge (*i.e.* the answer would not be explicitly provided in the texts and had to be inferred by participants). The same questionnaire was used as a post-test to measure learning outcome. Reliability analyses of the prior knowledge questionnaire showed a sufficient score (Cronbach’s alpha α = .71) as well as for the post-test score (Cronbach’s alpha α = .62).

Dependent variables collected

To analyze content pages processing *(i.e.* processing of the texts presenting in details each concept), we collected the number of different content pages visited (maximum = 10) and the time spent processing the content pages. To analyze the construction of the map, we retrieved the time spent building the concept map (*i.e.* time spent on all actions to create and transform the concept map such as moving concepts, creating/erasing links *etc.*) and the percentage of correct text-based and inference-based links between concepts created on the concept map. Text-based links corresponded to links that represented information explicitly mentioned in the content pages; whereas inference-based ones represented information that participants had to infer. A percentage score was calculated for each type of link in order to discriminate the proportion of correct and incorrect links created by participants. To do so, we retrieved the total number of text-based and inference-based links created by participants all along the activity (which included the number of links present on the final concept map but also the number of links that had been created and erased by participants). To determine whether links were correct or not, two matrixes that represented all explicit and inferential links between concepts were created. Correct links referred to links that connected two concepts that were semantically close and correct (as opposed to incorrect links that represented either incorrect or semantically distant information). We argue that this indicator might reflect to what extent participants were engaged in the elaboration of a text-based representation of the text (for text-based links) and a situational model (for inference-based links).

Participants

Fourty-nine psychology undergraduate students of the University of Toulouse volunteered in exchange for a 15 euros voucher (15 men and 34 women). Mean age was 21.41 (*SD*= 2.32). The data from 3 participants were removed as they spent less than one minute on their concept map.

Learning material and apparatus

The learning material consisted in a 754 words hypertext about water cycle in the environment that included ten nodes (*i.e.* ten content pages that referred to ten major concepts related to the topic). The hypertext was implemented on a concept mapping software specifically designed for this research. In the first homepage of the hypertext, the ten concepts were presented in ten separate boxes aligned in alphabetical order. Concepts labels were either plain text or a text illustrated with a picture depending on the condition (see Figure 2a and 2b below). Each concept box contained two icons: one to open up a content page presenting the concept in greater detail, and the second one allowed participants to move the concept box on the screen and build their map. Participants could access the ten different nodes of information by clicking on the “page” icon that was embedded in the concept boxes. When participants clicked on the “page” icon of a concept, the program displayed the content page that contained the text describing in details this particular concept. To construct their concept map, participants first had to drag and drop each concept box on the screen. Participants had to select each concept by clicking on the "hand" icon presented in the bottom-left of the concept box (see Figure 2 below) and move it on the screen at the desired place to organize the map's structure. Participants could move concepts as many times as they wanted. To draw connections between concepts, participants had to click on a particular concept and drag the mouse to another one in order to build a link (represented as an arrow). Participants could also label this connection by choosing between five possible labels ("is/are part of", "contribute(s) to", "cause(s)", "is/are used by", "pollute(s)". Double-clicking on an arrow erased the link and participants could change their concept map as they wanted.

The design of the software was made to be both intuitive and simple in order to foster easy interactions with the hypertext and support the elaboration of the concept map in an intuitive way. The software had two functions to help learners build their concept map. First, the ten main concepts of the learning material were already displayed on the screen at the beginning of the task so that participants could focus on processing the semantic relations between concepts (see Figure 2a and b). Secondly, the software facilitated the construction of links between concepts and the spatial organization of concepts on the map (by dragging and dropping the concept boxes with the mouse). The functionalities of the software were voluntarily limited so that building the concept map would not interfere too much with the comprehension task. In addition, the software allowed the inclusion of multimedia features such as pictures very easily (and consistently allowed their suppression for the control group). Eventually, after each learning session, the software recorded traces of participants' activity as a log file. Participants were free to stop their learning session whenever they wanted.

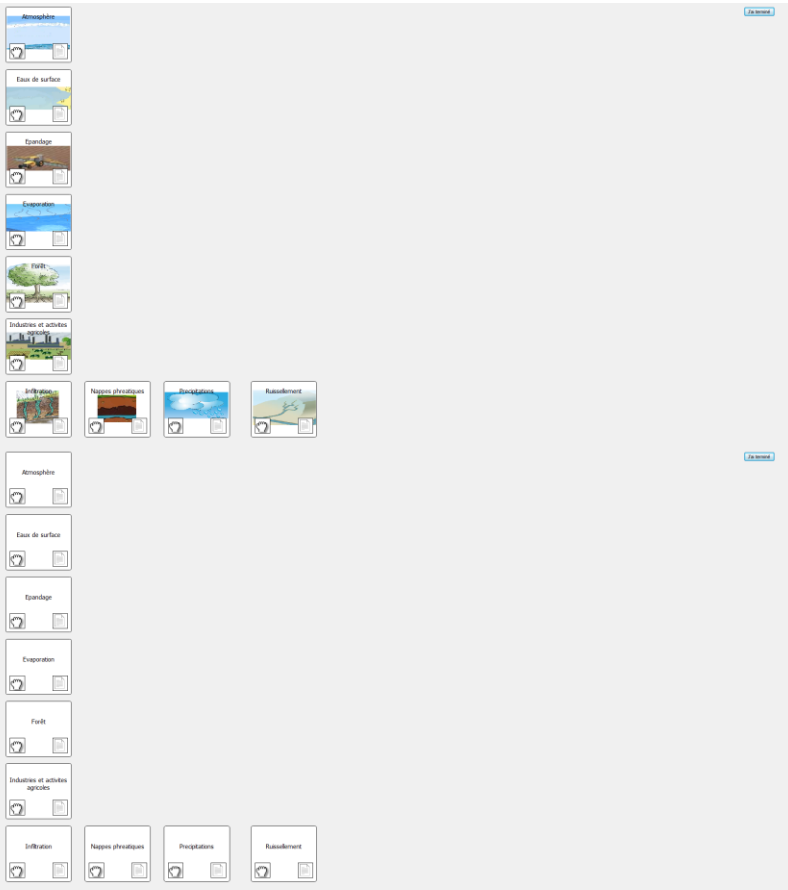

Figure 2a and 2b: concept mapping program used. The screenshots represent the initial display of the 10 concepts (picture and text condition 1a and text only condition 1b) (labels are in French as displayed in the original material).

In the multimedia presentation condition, two pictures depicted processes (*evaporation* and *water ingress*) and eight pictures depicted the main elements involved in the water cycle (*atmosphere*, *forest*, *industries*, *run-off water*, *rainfall*, *spreading surface waters*, *water tables*). The pictures representing processes provided information about the semantic relationships between several concepts (such as *surface waters* and *atmosphere* for the "*evaporation*" concept) and their respective spatial localization (for instance: *evaporation* takes place below *the atmosphere*). Pictures (and their textual label) were presented prior to the processing of the content pages (*i.e.* the texts describing in greater details the concepts) as concept labels. Although spatial and temporal integration of pictures and text is often more recommended to support better learning (Schüler, Arndt, & Scheiter, 2015), we decided to present pictures and their label first (and separately from the content pages) in order to avoid overloading learners' attention in the context of a concept map construction task. In addition, in lines with prior empirical showing that, under some circumstances, processing pictures prior to texts can affect subsequent text processing (Eitel et al., 2013), we expected the benefits of pictures to be more effective if presented before the content pages.

Norming study

In a norming study (with an online survey program *Qualtrics*), we tested to what extent the pictures selected were representative of the target concepts. Fifty-two undergraduate psychology students (mean age: M = 18.51, SD = 1.06) were presented with the ten concepts and ten labels in two different lists (in a randomized order). First, they were asked to associate each picture with its correspondent label. One point was granted when participants succeeded in associating the correct picture-label pair, whereas zero was granted when participants failed. Hence, the maximum score was ten. Secondly, participants were provided with the correct picture-label associations and were asked to rate how well each picture represents the concept on a 100% scale. Eventually, similar to a card sorting task, participants were asked to group pictures in several categories based on their semantic meaning. The goal of this task was to test our hypothesis that pictures would help learners categorize concepts at lower cognitive costs. To analyze the data collected, a matrix of co-occurrences was created to represent how many times each of all possible concept pair associations was observed (per participants). Then, a global matrix was computed to represent the percentage of occurrence of each concept association (see Appendix 1). Results of the norming study showed that participants succeeded in associating the ten pictures and concept labels together very well M = 8.73 out of ten, SD = 1.56, one sample t test: $t(52) = 38.13$, $p < .001$). Thus, they did not find it particularly difficult to interpret and understand the pictures used in the study. In addition, participants rated the strength of the semantic association between the pictures and the labels rather important (74.27 % out of 100%, SD = 11.48, one sample t test: $t(52)= 46.19$, $p < .001$), which tends to reflect that participants thought that the pictures selected depicted each concept to a very good extent. Finally, as illustrated in Appendix 1, the matrix of occurrences of the associations of pairs of concepts showed that the two processes (*evaporation* and *water ingress*) were frequently associated by participants (26.92% of participants connected those concepts $t(52) = 4.34$, $p < .001$). In addition, the concepts involved in these two processes were also most often associated (*evaporation-surface water* and *evaporation-atmosphere*, respectively 32.69 % one sample t test: $t(52) = 4.98$, $p < .001$ and 42.31% $t(52) = 6.12$, $p < .001$). Finally, the associations that were significantly most cited tackled concepts that shared close semantic connections (such as *rainfall* and *atmosphere* for instance: 46.15%, one sample t test: $t(52) = 6.62$, $p < .001$). Results of the norming study tended to confirm that the pictures selected in the learning material could really help learners identify concepts along with the semantic and spatial relationships that connect them.

Procedure

The experiment consisted of two different sessions. For the first one, students came to the lab and settled on the computer to fill in a questionnaire collecting demographic data (age, gender, studies, *etc.*) and the prior knowledge questionnaire. Then, participants performed a training session in which they had to get familiar with our concept map building program. They were instructed to try to construct a concept map in order to get familiar with the program in a self-paced manner (no time limit). The training session dealt with a new topic (dolphins) that consisted of three concepts (labels as plain texts only for the control group *versus* pictures + texts for the experimental group). During the second session, participants were instructed to build a concept map and learn as much as possible about the water cycle in order to complete a knowledge test.

2.2 Results

First, preliminary *t* tests analyses did not show any significant differences regarding prior knowledge between the two groups, $t(46) = .38$, $p = .70$. Participants in the text only group ($n = 25$) had a mean score of 4.92 (out of 8, $SD = 3.04$), whereas participants in the multimedia presentation group ($n = 21$) had a mean score of 4.57 ($SD = 3.09$). Next, to investigate how the presentation format of concepts during the elaboration of the concept map influenced the activity, we conducted ANCOVAS with presentation format as between subject factor and prior domain knowledge as covariable.

2.2.1 Impact of multimedia presentation and prior domain on information processing and map construction

The means and standard deviations of the different measures of text processing and concept mapping are presented in Table 3.

Table 3: Means and standard deviations for dependent variables related to content pages processing and map building.

	Text only condition (n = 24)		**Multimedia presentation condition** (n = 23)	
	M	*SD*	M	*SD*
CONTENT PAGES PROCESSING				
Total time spent processing the content pages (i.e. texts)	217.56	164.92	217.01	157.52
Number of different content pages visited	5.96	2.13	5.86	2.78
CONCEPT MAPPING				
Time spent building the concept map	149.38	86.36	192.28	140.49
Percentage of correct text-based links	21.66	1.27	30.63	1.27
Percentage of correct inference-based links	33.08	9.71	33.86	12.58

Content pages processing

Results of the ANOCOVAs showed no significant impact of multimedia presentation and prior knowledge on the number of different content pages consulted (max = 10), $F(2,46) = 3.16$, $p = .08$, $p < .07$, $\eta^2_p = .01$. In addition, no significant impact of the presentation format was observed on the time spent processing the content pages, $F(2,46) = .05$, $p = .82$. Only prior knowledge significantly reduced the time spent processing the content pages, $F(2,46) = 6.66$, $p = .01$, $\eta^2_p = .14$.

Concept mapping

Effect of multimedia presentation on the time spent building the concept map reached significance, $F(2,46) = 3.89$, $p = .05$, $\eta^2_p < .09$. Participants in the multimedia presentation condition spent more time building their concept map than participants in the text only condition (respectively $M_{sec} = 190.95$ $SD_{sec} = 24.85$ and $M_{sec} = 147.80$ $SD_{sec} = 22.76$). No significant effect of prior knowledge was observed on the time spent building the concept map, $F(2,46) = .07$, $p = .79$, $\eta^2_p < .01$. Regarding the quality of the links drawn by participants in their concept map, analyses investigated whether a multimedia presentation could support the construction of a greater number of correct text-based and inference-based links between concepts on the map. In average, participants built 15 links (multimedia condition: $M = 15.21$ $SD = .77$ and text only condition: $M = 15.15$ $SD = .81$; all $F < .01$). Effects of multimedia presentation was significant on the quality of the text-based information represented on the concept map $F(2,46) = 24.26$, $p < .001$, $\eta^2_p = .37$. In other words, participants in the multimedia presentation condition produced a greater percentage of correct text-based links than in the text only condition: (respectively $M_{\%} = 30.63$; $SD_{\%} = 1.32$ and $M_{\%} = 21.66$; $SD_{\%} = 1.27$ out of the total number of links created) and a smaller percentage of incorrect ones (text condition: $M_{\%} = 78.34$; $SD_{\%} = 3.93$, multimedia presentation: $M_{\%} = 69.37$; $SD_{\%} = 7.58$). Effect of prior domain knowledge was not significant, $F(2,46) = .20$, $p = .66$, $\eta^2_p < .01$. No significant effect was observed on the percentage of correct inference-based links created on the concept map (prior knowledge: $F(2,46) = 1.22$, $p = .28$, $\eta^2_p = .03$, presentation format: $F(2,46) = .25$, $p = .62$, $\eta^2_p = .01$).

2.2.2 Impact of multimedia presentation in concept mapping and prior domain knowledge on learning outcome

The analyses conducted on the post-test learning questionnaire did not show any effect of multimedia presentation format on the text-based scores $F(2,46) = .16$, $p = .69$, $\eta^2_p < .01$, or on the inference-based scores and $F(2,46) = .35$, $p = .56$, $\eta^2_p < .01$. See Table 2 below for means and *SDs*. Only prior domain knowledge increased both text-based $F(2,46) = 5.90$, $p = .02$, $\eta^2_p = .12$ and inference-based post-test score, $F(2,46) = 10.08$, $p < .01$, $\eta^2_p = .19$.

Table 2: Means and *SD*s for learning outcome and content pages processing.

	Text only condition (n = 25)		**Multimedia presentation condition** (n = 21)	
	M	*SD*	*M*	*SD*
Text-based posttest (max = 8)	5.21	1.44	5.29	1.35
Inference-based posttest (max = 8)	4.29	1.78	4.43	1.29

Intermediate discussion

This study investigated whether a multimedia effect can support concept mapping and learning. As we expected (H1c and H1d), results showed that multimedia effect increased the time spent building the map and the number of correct text-based links created. However, no impact was observed on content pages processing and learning outcome (unlike our expectations H1a and H1b). These findings pointed out that when concepts are illustrated with pictures, students engaged more actively in the elaboration of the concept map, focused more attention to represent the explicit links between concepts, but at the expense of inferential links. Pictures helped students create richer concept maps based on texts but they failed to support the elaboration of a more coherent situational model that integrate inferential connections between concepts (H2).

Based on these mixed results, we decided to replicate the present study with a more complex topic (*i.e.* concepts that would be less familiar for Human Sciences students). Indeed, although the pre-test questionnaire did not show that participants had a high amount of prior knowledge about the topic (*i.e.* mean score was about average), the different concepts tackled in the learning material may have seemed quite familiar and easy to understand for participants (for instance "*precipitations*, *water ingress*" may have seemed quite intuitively easy to understand). This phenomenon might also have been enhanced in the multimedia presentation condition in which simple pictures allowed the identification of concepts. In other words, multiple representations of seemingly easy-to-understand concepts might have let students to overestimate their prior knowledge and increase their overconfidence in learning (Kühl, Navratil, & Münzer, 2018). It may also have led participants to think that they had enough knowledge about the concepts (and more largely about the topic) and that they did not need to allocate extra resources to process more deeply the content pages. Eventually, shallow engagement and shallow processing may have conducted to low learning outcome and may have tempered the impact of the multimedia presentation of concepts on concept map building. The second experiment attempted to replicate the findings of experiment 1 with a more complex learning material (*i.e.* nitrogen cycle in the environment), in which pictures should be more useful to help students process less familiar concepts (such as *denitrification*, *fixation etc.*).

3. Experiment 2: Nitrogen cycle

3.1 Design

In experiment 2, the same procedure as experiment 1 was replicated (*i.e.* same *IV* and *DV*s)

Participants

Fifty undergraduate Psychology students of the University of Toulouse volunteered in exchange for a 15 euros voucher (14 men and 36 women). Mean age was 21.92 (SD = 3.31). The data from 3 participants were removed as they spent less than one minute on their concept map.

Learning material and apparatus

The learning material consisted in ten concepts of 547 words in total dealing with the nitrogen cycle in the environment. Reliability analyses of the prior knowledge and post-test questionnaires showed a sufficient score (Cronbach's alpha $\alpha = .70$ and $\alpha = .59$).

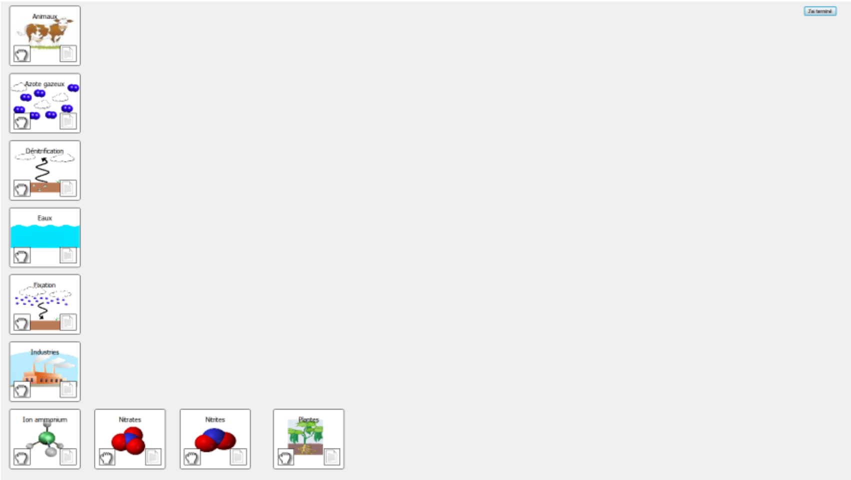

Figure 3: screenshot of the initial display of concepts in the concept mapping program (multimedia feature condition).

As stated in the previous intermediate conclusion section, experiment 2 tackled a more complex topic that includes some familiar concepts (*animals*, *plants*, *industries*) and less familiar and more abstract ones (such as *ammonium ions*, *nitrites*). In the multimedia presentation condition (see Figure 3 above), two pictures depicted processes (*denitrification* and *fixation*) and eight pictures represented four familiar concepts and four more abstract ones (respectively: *animals*, *industries*, *plants*, *water* and *ammonium ions*, *nitrates*, *nitrites* and *nitrogen gas*).

Norming study

In line with the protocol of experiment 1, a norming study was conducted with 22 undergraduate psychology students (mean age: M = 18.54, SD = 1.10). The same tasks were used (*i.e.* associate each picture with the corresponding label, rate to what extent each picture matches its label and categorize the pictures in different categories based on their meaning). Results showed that participants managed to associate each picture with its corresponding label very well (mean performance was 7.48 out of 10, SD = 1.85). Thus, they did not find it particularly difficult to interpret and understand the pictures used in the study (one sample t test: $t(22) = 19.33$, $p < .001$). In addition, participants rated the strength of the semantic association between the pictures and their labels rather important (68.23 % out of 100%, SD = 16.61, one sample t test: $t(22)= 19.70$, $p < .001$). Finally, as expected, results of the categorization task showed that the concept pairs that were mostly associated by participants were: the 2 processes (*i.e. denitrification* and *fixation* :70.83 %, $t(22)= 5.32$, $p < .001$), the 4 abstract complex concepts (between 25.00% to 70.83%, all $p < 0.2$) and the 4 more familiar concepts (between 20.83 % to 66.67%, all $p < 0.2$). See Appendix 2 for the complete Matrix of occurrences. These results tended to confirm that the pictures selected in the learning material could help learners identify and categorize concepts.

3.2 Results

Preliminary analyses revealed low prior knowledge scores and did not show any significant differences between the two groups ($t(47) = .84$, $p = .41$; multimedia presentation condition: $M_{\%} = 14.58$ $SD_{\%} = 12.04$ and text only condition: $M_{\%} = 11.41$ $SD_{\%} = 13.80$). As for the experiment 1, ANCOVAs including prior knowledge as covariate were conducted on the different dependent variables.

3.2.1 Impact of multimedia presentation and prior domain on information processing and map construction

The means and standard deviations of the different measures of content pages (*i.e.* texts) processing and concept mapping are presented in Table 4.

Table 4: Means and standard deviations for dependent variables related to content pages processing and map building.

	Text only condition (n = 24)		**Multimedia presentation condition** (n = 23)	
	M	*SD*	M	*SD*
CONTENT PAGES PROCESSING				
Total time spent processing the content pages (i.e. texts)	210.65	146.24	242.39	156.62
Number of different content pages visited	5.63	.33	6.04	.34
CONCEPT MAPPING				
Time spent building the concept map	113.50	23.45	194.90	23.96
Percentage of correct text-based links	24.92	6.67	34.63	6.28
Percentage of correct inference-based links	11.53	3.93	11.55	5.45

Content pages processing

Results of the ANCOVAS showed that participants in the picture condition significantly read a greater number of content pages than participants in the text only condition, $F(2,47) = 3.95$, $p = .05$, $\eta^2_p < .08$ (respectively $M = 6.04$ $SD = .34$ and $M = 5.63$ $SD = .33$ out of ten). No significant impact of prior knowledge was observed, $F(2,47) = .42$, p = ns. No significant effects of multimedia presentation and prior knowledge were observed on the time spent processing the content pages, respectively $F(2,47) = 1.80$, $p = .19$ and $F(2,47) = .59$, $p = .45$.

Concept mapping

Regarding the time spent building the map, results of the ANCOVAs showed that multimedia presentation increased the time spent building the concept map, $F(2,47) = 5.85$, $p = .02$, $\eta^2_p < .12$. No significant effect of prior knowledge was observed, $F(2,47) = .06$, $p = .82$, $\eta^2_p < .001$. In average, participants built 18 links (multimedia condition: $M = 18.13$ $SD = 4.60$ and text only condition: $M = 18.52$ $SD = 4.79$; all $F < .01$). Results showed that the multimedia presentation condition improved the quality of the representation of text-based information on the concept map, $F(2,47) = 24.59$, $p < .001$, $\eta^2_p = .36$. In other words, participants in the multimedia presentation condition created a larger percent of correct text-based links between concepts (respectively $M_{\%} = 34.60$ $SD_{\%} = 1.39$ and $M_{\%} = 24.97$ $SD_{\%} = 1.40$) and reduced the proportion of incorrect text-based links (text only: $M_{\%} = 75.08$ $SD_{\%} = 6.67$ and multimedia presentation: $M_{\%} = 65.37$ $SD_{\%} = 6.27$) than participants in the text only condition. Prior knowledge did not have any significant impact on the percentage of correct text-based links created, $F(2,47) = .13$, $p = .72$, $\eta^2_p < .01$. No significant effects were observed on the number of correct inference-based links between concepts created (prior knowledge: $F(2,47) = .06$, $p = .81$, $\eta^2_p < .001$, presentation format: $F(2,47) = 1.64$, $p = .21$, $\eta^2_p < .04$).

3.2.2 Impact of multimedia presentation in concept mapping and prior domain knowledge on learning outcome

Results of the ANCOVAs did not reveal any significant effects of prior knowledge or of presentation format on the text-based post-test scores (all *F*s < 1; multimedia presentation: M = 4.65 SD = 1.30; text only condition: M = 4.74 SD = 1.32 out of 8) as well as on the inference-based post-test scores (all *F*s < 1; multimedia presentation: M = 1.91 SD = 1.54; text only condition: M = 2.46 SD = 1.38 out of 8).

Table 4: Summary of the significant impact of prior knowledge and presentation format (P+T = pictures + text; T= text only) in the two experiments

	Experiment 1 Water cycle		Experiment 2 Nitrogen cycle	
	Prior knowledge	Presentation format	Prior knowledge	Presentation format
Learning outcomes				
Text-based post-test score	*	*ns*	*	*ns*
Inference based post-test score	*	*ns*	ns	*ns*
Concept processing				*ns*
Number of different content pages consulted	^	*ns*	*ns*	* P+T > T *ns*
Time spent processing the content pages	*	*ns*	*ns*	
Concept map building				
Time spent building the concept map	*ns*	* P+T > T	*ns*	* P+T > T
% correct text-based links between concepts	*ns*	* P+T > T	*ns*	* P+T > T
% correct inference-based links between concepts	*ns*	*ns*	*ns*	ns

* $p < .05$ ^ $.10 < p < .05$

4. General discussion

These two studies examined how multimedia effect (*i.e.* presentation of concepts in pictorial and textual formats) can affect concept mapping, information processing and learning outcome. Participants had to build a concept map in order to learn about a topic either with a textual-only material (*i.e.* concept labels presented as textual labels) or with a multimedia presentation (*i.e.* concept labels presented as textual labels and illustrated with a relevant picture). To the best of our knowledge, these studies are the first to provide clear evidence that a multimedia presentation of concepts in a concept mapping task can support learners' engagement in the elaboration of the concept map. Table 4 above provides a general overview of the two studies' findings.

In line with hypothesis 1, original findings of the two studies confirmed a multimedia effect on learners' engagement in the elaboration of the map. As postulated by the multimedia theory (Mayer, 200), results tended to show that adding pictures to the learning material increased the time spent building the concept map (H1c). In addition, the multimedia presentation of concepts also seemed to have served as a mental scaffold to support better integration of text-based information as it increased the number of correct text-based links created between concepts (H1d) (and consequently reduced the proportion of incorrect text-based links created). Consistently with theoretical models (Schnotz, 2002), multimedia effect in concept mapping most likely fostered the extraction of more information from the different content pages and the elaboration of a more coherent and semantically richer macrostructure of the document (as represented by the enhanced quality of the map built on a text-based level). This pattern does tend to replicate the benefits of multimedia presentation on relational processes and information integration in concept mapping (Mayer, 2006; Roessger et al., 2018). In addition, experiment 2 confirmed prior findings showing that perceptual clues (provided by the pictures) can facilitate hypertext processing (Pirnay-Dummer, & Ifenthaler, 2011; van Amelsvoort et al., 2013). Indeed, participants in the multimedia presentation condition processed the content pages of the hypertext more extensively (they visited a greater number of different content pages) (H1a and b). This richer exploration of the hypertext most likely reflects that learners in the multimedia presentation condition attempted to make more connections between content pages (and concepts) than in the text only condition. However, making better text-based connections between concepts does not necessarily imply that learners construct a more coherent mental representation that includes inferential connections between concepts (and their own prior knowledge). Indeed, in line with a prior study (Morfidi et al., 2018), no main impact of multimedia effect in concept mapping was found on learning outcome. Prior studies showed that concept mapping can be beneficial only if learners allocate enough resources to strategically process it (Salméron et al., 2009). In line with this finding, some of the results presented in the two present studies may explain why no significant impact of concept mapping with a multimedia presentation of concepts was observed on learning outcome (unlike hypothesized H2). First, participants mostly engaged in the construction of the map but they did not process the content of the hypertext in great details (*i.e.* they visited a small amount of content pages and did not visit all pages available). Secondly, as documented in literature, instructions can have a tremendous impact on learners' behavior and performance achievement. In our study, participants were instructed to spend time building a concept map in order to learn about a given topic. Yet, some participants may have developed the idea that building the concept map was the main task. Thus, participants may have allocated resources to the creation of the map but did not use their concept map as a tool to memorize information. Hence, shallow engagement in the learning part of the task or cognitive overload may explain the absence of main effects on learning performance. In addition, this pattern could also be explained by the relatively average amount of prior knowledge that participant had. In a nutshell, results showed that a multimedia effect can occur in a concept mapping task and can support hypertext exploration, engagement in the elaboration of the map and it can facilitate relational processes on a text-based level. Consistently with prior findings, the two studies failed to show a significant main impact of the multimedia presentation on learning outcome (Morfidi et al., 2018; Salméron et al., 2009).

Limitations and future research

The first limitation of the two experiments lies in the dependency of the results to the specific knowledge domains tackled in the two hypertexts and the functionalities of the software designed. As a reminder, experiment one tackled concepts related to the water cycle in the environment. Although some concepts of the learning material could be complex for non-biology students, the topic may have been or seemed too easy for participants. As discussed in the intermediate conclusion of experiment 1, the water cycle might have led participants to over-estimate their prior knowledge about the topic, and/or to think that they had put enough efforts into the map construction (and hence they did not need to process information contained in the content pages in greater details). In addition, in the experiment 1, the concepts in the water cycle may have been more transparent and familiar for learners. In terms, the pictures provided in the learning material may have been redundant with participants' prior knowledge and they were thus less relevant. Hence, multimedia effect may have been less effective because the pictures in the learning material were actually more decorative than informative (Lenzner et al., 2013). Consequently, both shallow processing of the hypertext and the lack of critical importance of pictures may explain, at least partially, why mixed effects of the concept map and multimedia effect were observed on learning outcome in experiment 1. The findings of the present experiments are also to be related to the functionalities of the software designed. Indeed, one may argue that the multimedia features included in the concept mapping software (*i.e.* integrating pictures as concept labels) are quite simple. However, in line with findings from prior studies, building a concept map can be a difficult task and can increase extraneous processing that can be detrimental for learning, especially for learners with low prior topic knowledge (Amadieu et al., 2015; Schroeder et al., 2017). Hence, to investigate to what extent multimedia features could support the elaboration of a relevant concept map (and in terms support learning outcome), we argue that such multimedia features should remain simple so that they do not require too much resources that would be needed for germane processes that are essential for learning (Ayres & Sweller, 2014; Sweller, 1994). Yet, the design of the software used in the two present studies raises a second potential limitation regarding the presentation of pictures in the learning material. As a reminder, pictures were displayed prior to the content pages and were no longer available when participants opened up a content page. Consequently, the temporal and spatial disrupted presentation of pictures may have required an increase amount of cognitive resources in working memory. First, because to integrate the pieces of information extracted from the pictures from the different content pages, participants had to rely on their representation of the pictures as stored in their memory. Secondly, disrupted presentation of pictures can cause more eye-transitions between content pages and pictures. In addition to these cognitive costs, presenting both information sources separately can also induce a split-attention effect that can hamper learning (as compared to when sources of information are temporally and physically integrated Ayres & Sweller, 2014).

Future works should integrate pictures in the content pages (*i.e.* so that the pictures are always available and learners can switch more easily between the two sources of information to integrate relevant information). To generalize these findings, studies should also investigate the multimedia effect in concept mapping with learners of varying level of prior knowledge and in more complex hypertexts (*i.e.* containing a larger number of content pages). In addition, to further expand our knowledge about multimedia effect on concept mapping, future works should also explore the impact of more multimedia features. For instance, studies could investigate how the integration of dynamic visual representations (such as animated pictures) may help learners elaborate a more coherent concept map that would promote better learning outcome. Empirical studies have shown that videos and animations may be well suited to elaborate a coherent mental representation when the learning material involves temporal dimensions (Tversky, Morrison, & Betrancout, 2002) (*i.e.* for mechanisms that involve changes over time such as such as nitrogen transformation in the environment or the development of greenhouse gas). Such concept mapping tools could for instance provide a clickable static picture that provides a general overview of the animated picture and which can be used to access the animation upon a click of the user. Overall, implications of this work provide new evidence that multimedia presentation of concepts can help low knowledgeable learners build more coherent concept map. However, more investigations are needed to design instructional material supporting concept mapping and to understand the conditions under which concept mapping supports learning outcomes.

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Appendixes

Appendix 1: Matrix for the percentage of occurrence of concept pair associations for experiment 1 (bold letters associations significantly more cited by participants, *: $p < .01$)

	Atmosphere	Surface waters	Agricultural spraying	Evaporation	Forests	Industries and agr	Water ingress	Water tables	Rainfall	Water run-off
Atmosphere										
Surface waters	**32,69***									
Agricultural spraying	3,85	0,00								
Evaporation	**42,31***	**32,69***	1,92							
Forests	**7,69**	5,77	**25***	1,92						
Industries and agriculture	3,85	1,92	**80,77***	0,00	**26,92***					
Water ingress	**7,69**	**11,54**	5,77	**26,92***	**23,08***	**9,62**				
Water tables	**28,85***	**26,92***	3,85	**7,69**	**13,46**	1,92	**42,31***			
Rainfall	**46,15***	**30,77***	5,77	**36,54***	3,85	1,92	**25,00**	**15,38**		
Water run-off	**13,46**	**30,77***	1,92	**34,62***	**7,69**	1,92	**46,15***	**30,77***	**36,54***	

Appendix 2: Matrix for the percentage of occurrence of concept pair associations for experiment 2 (bold letters associations significantly more cited by participants, *: $p < .01$)

	Animals	Nitrogen gas	denitrification	Waters	Fixation	Industries	Ammonium ions	Nitrates	Nitrites	Plants
Animals										
Nitrogen gas	0,00									
Denitrification	8,33	**29,17***								
Waters	**45,83***	8,33	12,50							
Fixation	4,17	**33,33***	**70,83***	8,33						
Industries	**20,83**	8,33	0,00	12,50	12,50					
Ammonium ions	8,33	**33,33***	0,00	0,00	0,00	4,17				
Nitrates	4,17	**25,00**	0,00	0,00	0,00	4,17	**58,33***			
Nitrites	4,17	**33,33***	0,00	8,33	8,33	0,00	**54,17***	**70,83***		
Plants	**66,67***	0,00	8,33	**50,00***	**50,00***	8,33	0,00	0,00	0,00	