Using pop-up windows to improve multimedia learning

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Abstract The aim of the present study is to evaluate the effects on learning of the spatial integration of textual information incorporated into illustrations in the form of pop-up windows that are opened by the user. Three groups of students viewed illustrated texts depicting the functioning of the heart and the replication of the AIDS virus either with textual information presented below the picture, with textual information integrated within the picture, or with textual information integrated within the picture with pop-up windows. The results showed that the integrated formats were more effective than the separated format when we tested the retention of textual information, comprehension and the matching of textual elements to the appropriate illustrated elements. Furthermore, they indicated that the group working with pop-up windows performed better than the integrated groups on the retention test for illustrated information as well as when asked to find correct solutions to problems in a comprehension test. Consequently, these findings support the use of pop-up windows in learning with this kind of illustrated explanatory text.

Keywords cognitive psychology, instruction, multimedia, post-graduate.

Introduction

Since the 1970s, many studies have focused on learning with illustrated documents. Globally, these studies have shown that the addition of an illustration to a text significantly improves memorization performance (Levie & Lentz 1982). More recently, studies of the effects of illustrations have tended to focus more on the understanding of educational and technical documents. Taking models of text comprehension (Johnson-Laird 1983; Kintsch 1998) as a starting point, a number of researchers have tried to evaluate the effects of the presence of illustrations on the elaboration of mental representations in response to complex documents. According to Schnotz *et al*. (1999), the processing of an illustrated document follows two distinct paths: a descriptive path (or symbolic path) dedicated to the processing of the text; and a depictive path (or analogical path), which is involved in the processing of the illustration. In the descriptive path, the processing activities applied to the text are similar to those performed in models of text comprehension, i.e. a surface representation and a text base. Following new processing activities, the text base enables the construction of a mental model that is located in the depictive path. In the depictive path, the processing of the illustration results in a visual representation followed by a mental model. The processing of the textual and illustrated elements within the descriptive and depictive paths, respectively, makes it possible to develop a single mental model.

Many studies on illustrated documents have confirmed the impact of illustrations during the construction of a mental model. In the first of these (Mayer 1989), students read a passage about vehicle

Accepted: 3 February 2006
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braking systems that either contained labelled illustrations of the systems, illustrations without labels, labels without illustrations or no labelled illustrations. Students who viewed documents that contained labelled illustrations of braking systems performed better than the control groups when required to transfer their problem-solving activity.

Mayer and Gallini (1990) asked novice students to study a document dealing with the functioning of several pump systems. This document was presented under four different conditions: an unillustrated condition consisting of a descriptive text and an explanatory text, a condition containing a descriptive text accompanied by an illustration, a condition with an explanatory text accompanied by an illustration and, finally, a condition including descriptive and explanatory texts accompanied by an illustration. The results clearly indicated that the novice learners who had been exposed to the condition with the descriptive and explanatory texts accompanied by an explanatory illustration obtained better conceptual recall and problem-solving performances than their counterparts who had been exposed to the unillustrated condition. Other studies have made it possible to confirm these results by revealing the positive effects of illustrations on students' ability to draw elaborate inferences from the illustrated text (Glenberg & Langston 1992; Gyselinck & Tardieu 1999; Gyselinck *et al*. 2000).

To learn a document consisting of a spatially separate text and illustration, students must necessarily reconstruct for themselves the referential links between the textual and illustrated elements. Consequently, they are required to move many times between the textual elements and the corresponding illustrated elements in order to understand the ideas conveyed by the document. In the long term, the implementation of these movements between the various elements risks disturbing the processing of the information in the document and, consequently, may degrade the relevance and coherence of the mental model. In the literature, this phenomenon of switching between the text and the illustration has been examined particularly extensively in the work of Sweller (Sweller & Chandler 1991; Chandler & Sweller 1992; Sweller 1999) under the name of the split attention effect. According to this author, the split attention effect arises when two spatially separated sources of information – in the case in point, a text and an illustration – have to be learned simultaneously. In order to perform this mental integration, learners have to move frequently between the textual elements and the illustrations. A number of studies which have made use of eye-tracking techniques have reported the existence of these movements (Hegarty & Just 1993; Hannus & Hyönä 1999). To overcome this problem of dividing attention between two sources of information, Sweller (1999) recommended integrating the text units in the corresponding pictorial units. This is the process of the spatial integration of information. This process is described in detail by Mayer (2001), who refers to it as the spatial contiguity effect. According to these authors, the restoration of the explicit relations between the text and the illustration significantly improves the relevance of the mental model constructed on the basis of the document. Thus, Sweller and co-workers were able to reveal an improvement in performance as a result of the spatial integration of information in a large number of studies involving topics as diverse as geometrical principles (Sweller *et al*. 1990), human anatomy (Chandler & Sweller 1991) the use of computer software (Chandler & Sweller 1996) or electricity (Chandler & Sweller 1991). In this latter study, the subjects saw two formats of an illustrated document explaining the functioning of electrical circuits: a separated format in which the textual information was presented below a diagram, and an integrated format in which the textual information was directly integrated within a diagram. The results showed that in written and practical tests, the subjects who saw the integrated format performed better than those who saw the separated format. Similarly, Mayer and collaborators have conducted a considerable volume of research intended to evaluate the effects of reconstructing the explicit links between textual and visual information on the learning of complex documents. In a summary of four different studies, Mayer (1997) has shown that spatial contiguity between text and illustration helps improve the creativity of the solutions proposed by learners by more than 70%. These conclusions are set out most clearly in a study conducted by Mayer *et al*. (1995). In this study, the authors asked novice subjects to learn a document dealing with the formation of storms. The document consisted of a text and five illustrations presented in one of two conditions: a separated condition in which the text elements and the illustrations were presented on two different pages, and an integrated condition in which the textual elements were presented below the corresponding illustrations. The authors observed that the subjects in the integrated condition outperformed those in the separated condition in a transfer task. The studies presented so far were conducted using paper media. However, other research has shown that the benefits associated with the spatial integration of information can be transferred to electronic documents. Thus, Jamet (2000) tested the effects of the spatial integration of information in two electronic documents relating to the functioning of the eye and the ear, respectively. These documents were presented in two formats: a separated format in which the text was located below the illustration, and an integrated format in which the text was directly integrated with the illustration. The results suggest that the subjects' performances in response to inferential questions were significantly better when they had been exposed to the integrated rather than the separated format. Similarly, subjects using an integrated format consulted documents more rapidly than those confronted with a separated format. The various studies presented above suggest that the restoration of the explicit links between the text and the illustration helps improve the quality of the mental representations generated by the use of an illustrated document. Nevertheless, Bétrancourt and Caro (1998) have tended to moderate this idea by suggesting that the process for the spatial integration of information is relevant only in the case of documents that possess a small amount of text. In effect, these authors observed that the integration of a sizeable text with an illustration can induce a perceptual overload effect and, as a result, impair the development of a relevant mental representation.

In an attempt to overcome the difficulties of text/illustration coreferencing, some studies have investigated the possibilities of interactive electronic environments. By giving learners the possibility of controlling the presentation of information, these environments encourage them to engage in the completion of the task and, as a result, improve the quality of their mental representations. The beneficial effects of these interactive environments on the restoration of the referential links between texts and illustrations can be seen, in particular, in the research conducted by the team headed by Bodemer. In a study using statistics courses document, Bodemer *et al*. (2004) showed that a drag & drop format requiring the active integration of the text in the illustration improved subjects' performances in terms of memorization, visual comprehension and verbal comprehension when compared with a format in which the illustration and the text were separated or integrated.

To summarize, there are various ways of restoring the referential links between text and illustration: explicitly, through the spatial integration of the textual information in the corresponding illustrated information, or implicitly by encouraging learners to engage in the completion of the task. Taking research into spatial integration and interactive environments as their starting point, Bétrancourt and Caro (1998) proposed a new process for restoring the referential links between text and illustration: pop-up windows. The use of these pop-up windows during the learning of an illustrated document makes it possible to combine all the advantages of the two processes described above while avoiding some of the associated drawbacks. According to Bétrancourt and Caro (1998), pop-up windows would thin down the density of the information permanently present on screen. They would also imply that learners have to be active when consulting a text. Finally, this tool would make it possible to make the links between the text and illustrated elements explicit. In order to examine the effectiveness of this new spatial integration process, Bétrancourt and Bisseret (1998) asked novice subjects to learn a technical document relating to smoke conduits. This document was presented on three different formats: a conventional format in which the textual explanations and the illustration were presented separately; an integrated format in which the explanations were presented inside the diagram; and finally a pop-up format in which the explanations were integrated by means of pop-up windows. The results indicated that during the learning phase, the subjects confronted with the pop-up windows format were more efficient in associating the text elements with the corresponding illustrated elements than those in the conventional condition. During the final phase, the authors observed that the subjects in the pop-up windows and integrated conditions were faster than those in the conventional condition when asked to respond to indexed recall tasks. Thus, the spatial integration of information using pop-up windows seems to facilitate the co-referencing of the text and illustrated elements. These benefits brought by the use of pop-up windows have also been confirmed in a study conducted by Bétrancourt and Bisseret (1998) relating to the acquisition of a procedure designed to help students understand and reproduce 'ABACUS' schemas. This technical document, which consisted of an explanatory text and a graphic, was presented in three different formats: a conventional format in which the text and graphic were separate; an integrated format in which the text information was presented close to the graphical information; and, finally, a pop-up format in which the text information was again integrated in the diagram by means of pop-up windows. The results showed that there was no effect of presentation format on the performances during the learning phase. Similarly, there was no significant difference between performances on inverted problems as a function of the format in which the information was presented. In contrast, the subjects in the pop-up windows and integrated conditions performed better on transfer problems than the subjects in the conventional condition.

In conclusions, the use of pop-up windows as a spatial integration tool makes it possible to improve text/illustration co-referencing and thus results in an improvement of subjects' performances in terms of the memorization of associations between the text and the illustration, the speed of response and the transfer of knowledge, when compared with the use of a conventional format. However, a careful re-examination of this research reveals no beneficial effect of the pop-up windows format when compared with the integrated text/illustration format. Thus, contrary to the predictions made by Bétrancourt and Bisseret (1998), the disappearance of the perceptual overload and the increase in the level of interaction with the environment do not help improve students' learning performance. Given the current state of our knowledge, it would be premature to conclude that the pop-up windows format has no beneficial effect compared with the integrated format as only a small number of studies have investigated this type of spatial integration of information.

Experiment

The aim of this study was to evaluate the effects of the different processes used for the spatial integration of information on the learning of educational documents. To do this, we compared three types of information presentation format: text separated from the illustration; text integrated with the illustration; and, finally, text in pop-up windows integrated in the illustration. The choice of these formats was directly inspired by the studies conducted by Bétrancourt and Bisseret (1998) and Bétrancourt and Caro (1998). Firstly, this experimental design will allow us to test the hypothesis that documents that favour the spatial integration of information permit the restoration of text/illustration co-referencing. If the spatial integration of textual and illustrated information improves the co-referencing of the text and the illustration, then learners' performances in terms of comprehension (evaluated by inferences and diagrams in which the text is moved to the corresponding parts of the image) should be better when they use the pop-up windows and integrated formats than when they are confronted with the conventional format. In contrast, the performances obtained by learners when asked to memorize literally the text elements (paraphrases) and illustrated elements (completion of schemas) should not be affected by the restoration of the explicit links between the text and the illustration.

In this study, a distinction will be performed between the effects of a pop-up windows format and to those induced by an integrated format. If these two processes of spatial integration do not lead to equivalent learning performances, then the restoration of text/illustration co-referencing is not sufficient to explain the differences. It may then be necessary to turn to other explanatory hypotheses such as the disappearance of perceptual overload or interaction with the learning environment. This study also attempts to provide fresh observations with the aim of better identifying the benefits of pop-up windows.

Method

Subjects

Seventy-two psychology students in first, second and third degree levels at the University of Rennes 2 took part in this experiment. All the participants volunteered to cooperate in the research. Our study group consisted of 11 males and 61 females aged between 18 and 25 years. We had previously checked that they had received no instruction concerning the subject matter that we intended to examine in their university courses.

Material

The experimental material consisted of two educational documents relating to the functioning of the heart and the replication of the AIDS virus, respectively. These documents were presented via an electronic interface using three different information presentation formats: a separate text and illustration format; an integrated text and illustration format; and a format in which the text was integrated in the illustration by means of pop-up windows (see Fig 1).

The textual and illustrated information was identical in the various formats – only the layout changed. These interfaces were developed using Macromedia director MX® software.

Procedure

The experiment took place in a computer room equipped with four compartments. On arrival, the subjects were randomly assigned to one of the three experimental conditions. In order to make sure that the subjects complied with the study participation criteria, they were asked to fill in an information form allowing us to check their age, academic career and school-leaving examinations.

Once they had completed this form, the participants started the first phase of the study. During this initial phase, the subjects had to complete a prior information questionnaire This questionnaire contained 10 questions: five relating to the heart and five relating to AIDS. Their performances on this prior knowledge questionnaire determined whether or not they could proceed to the second phase of the study. Thus, participants who obtained a score better than 2.5 points out of 5 on either of the topics in the pre-

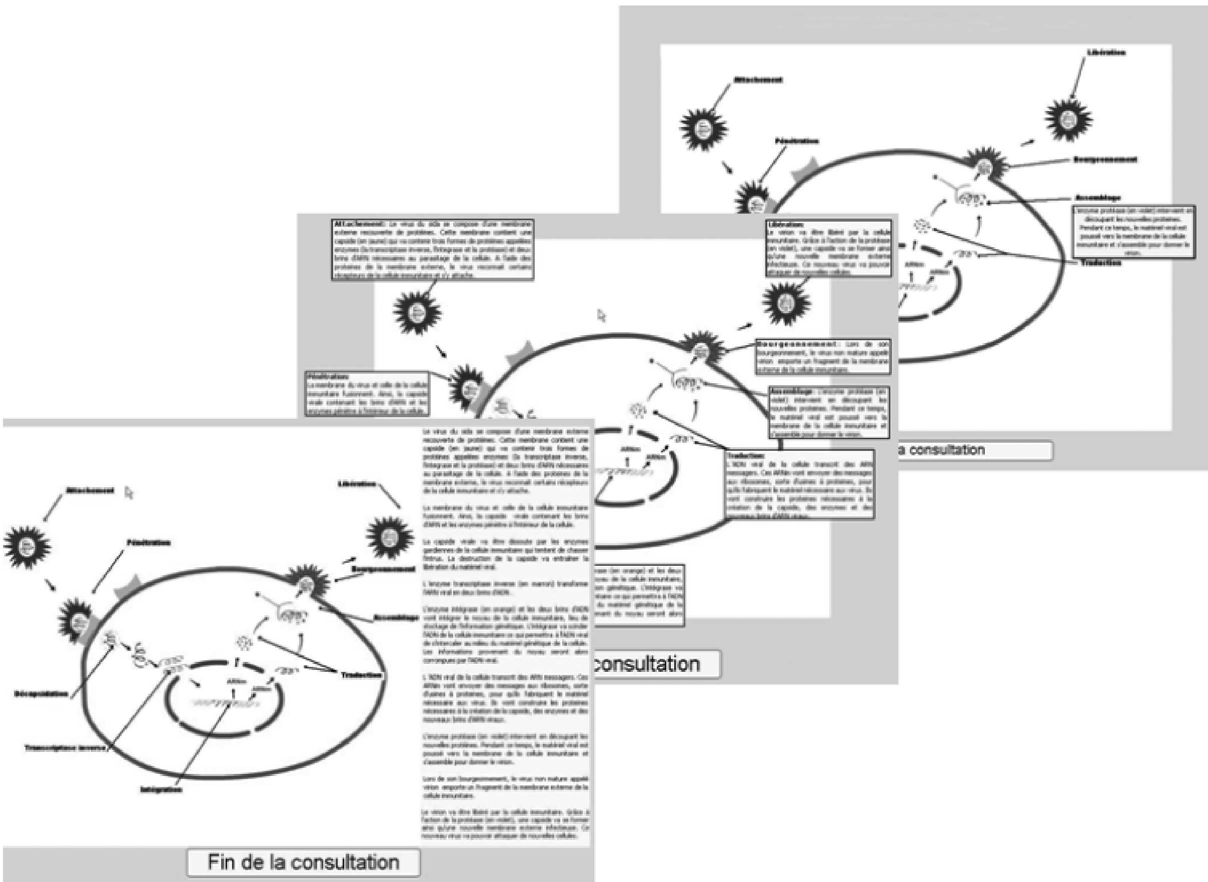

Fig 1 Presentation of the experimental material with, from left to right, the separated, integrated and pop-up formats.

questionnaires were considered to possess too much prior knowledge and were consequently excluded from our analyses.

In the second phase of the study, the subjects had to view the first of the two educational documents. The order of presentation of the documents as well as the presentation formats were counterbalanced. The experiment started with the reading of the instructions. This instruction informed the subjects that the viewing time was limited to 10 min and that their knowledge would be evaluated at the end of the viewing. In the condition involving pop-up windows, the subjects were told that they had to click on the labels (light-coloured words in bold print). To avoid handling problems, these subjects trained using a 'pop-up test' located at the bottom of the page. Once the subjects had read the instructions, they clicked on the 'Start' button to start the learning exercise. As mentioned above, the viewing time was limited to 10 min. This time limit was set following the observation that subjects very rarely view documents beyond this limit. However, if the subjects thought they had memorized and understood the entire document before the permitted time had expired, they could exit the learning interface by clicking on the 'End viewing' button.

The third phase started when the learning of the document was complete. At the end of the viewing phase, the subjects accessed a new page in which they were instructed to respond to a questionnaire that they would find face down nearby. This questionnaire consisted of two types of questions. Five paraphrase questions were posed in order to measure the memorization of textual information ('What do the superior and inferior caval veins do?'), while five inference questions were used to test the students' ability to draw elaborate inferences from the mapping of textual and illustrated information ('If the walls of my myocardium are no longer irrigated, what could the reason be?'). In other words, these questions made it possible to evaluate the comprehension of the information.

This questionnaire also required the subjects to complete two types of diagram: a 'text-illustration paraphrase diagram' and a 'diagram completion'. The 'text-illustration paraphrase diagram' was used to evaluate the aptitude of the subjects to reconstruct the referential links between textual and illustrated information effectively. This task consists in using numbers to match four text passages with the corresponding parts of the illustration. The 'diagram completion' task was designed to measure the memorization of illustrated elements. In this type of task, subjects have to replace four legends in the illustration correctly. Once they had completed the questionnaire, the experimenter asked the subjects to learn the second document. The procedure used for this second document was identical to that described for phases 2 and 3.

Results

Prior knowledge test

Levene's homocedasticity test revealed no significant heterogeneity between the variances on the scores in the prior knowledge tests for the heart ($F(2, 69) = 1.24$, $P = 0.30$) and AIDS ($F < 1$). The mean scores on the prior knowledge test for the heart were 0.74 ($\text{SD} = 0.54$) for the separated format, 0.72 ($\text{SD} = 0.72$) for the integrated format and 0.63 ($\text{SD} = 0.54$) for the pop-up windows format, respectively. An ANOVA conducted on the subjects' performances in the heart pre-test revealed no significant difference ($F < 1$).

As far as the AIDS prior knowledge test was concerned, the mean scores were 1.24 ($\text{SD} = 0.91$) for the separated format, 1.20 ($\text{SD} = 0.82$) for the integrated format and 1.25 ($\text{SD} = 0.90$) for the pop-up windows format. As for the heart pre-test, the performances of the subjects in the AIDS pre-test revealed no significant difference ($F < 1$).

Analysis of the effects of the format factor on the questions

Both the paraphrase-type questions and the inference-type questions were scored out of 10 points. For each of the questions, the subjects could achieve a score of 0 point, 0.5 point or 1 point (Table 1).

Paraphrases

Levene's homocedasticity test indicated significant heterogeneity between the variances on the paraphrase scores, $F(2, 69) = 3.30$, $P < 0.05$. Consequently, these performances were analysed using a nonparametric Kruskal–Wallis test. This latter test revealed a significant effect of the information presentation format on subjects' memorization performances, $H = 6.59$,

Table 1. Mean performances on paraphrase- and inference-type questions.

Format	Paraphrases		Inferences		
	M	SD	*M*	SD	*n*
Separated	4.67	1.95	3.46	1.96	23
Integrated	6.00	2.04	4.00	1.68	25
Pop-up	6.14	1.35	4.97	1.71	24

$N = 72$, $P < 0.05$. A more thorough analysis using a Mann–Whitney test indicated a significant difference between the separated group ($M = 4.67$, SD $= 1.95$) and the integrated group ($M = 6.00$, SD $= 2.04$), Mann–Whitney $U[48] = 188.5$, $P < 0.05$. Similarly, the performances of the separated group ($M = 4.67$, SD $= 1.95$) were significantly poorer than those of the pop-up windows group ($M = 6.14$, SD $= 1.35$), Mann–Whitney $U[47] = 164.5$, $P = 0.01$. In contrast, the performances obtained for the integrated and pop-up windows formats did not differ significantly for the paraphrase questions, Mann–Whitney $U[49] = 288$, $P = 0.81$.

Inferences

After checking that the homocedasticity of the variances was respected ($F < 1$), an analysis of variance on the performances was performed on the inference questions. This latter revealed a significant effect of the format on the inference scores, $F(2, 69) = 4.41$, $MS_e = 3.18$, $P = 0.01$. Using an LSD-type comparison, the performances of the subjects in the pop-up windows format ($M = 4.98$, SD $= 1.70$) were better than those of the subjects in the separated format ($M = 3.46$, SD $= 1.96$), $MD = 1.52$, $P < 0.01$. As expected, the scores obtained by the subjects in the pop-up windows condition ($M = 4.98$, SD $= 1.70$) were greater than those of the subjects in the integrated condition ($M = 4.00$, SD $= 1.67$), $MD = 0.98$, $P = 0.05$. In contrast, the comprehension scores obtained by the subjects in the separated group ($M = 3.46$, SD $= 1.96$) did not differ significantly from those obtained by the subjects of the integrated group ($M = 4.00$, SD $= 1.67$), $MD = 0.54$, $P = 0.29$.

Analysis of the format factor on the schemas

In this part of the analysis, the effects of the format on the schemas were tested using a logistic regression more suitable to Bernouli-type variables, i.e. dependent variables with the values [0,1] (McCullagh & Nelder 1983). In effect, for the text-illustration paraphrase schemas as for the diagram completions, scores were between 0 and 1 for each of the four items presented (Table 2).

Text-illustration paraphrase schemas

Firstly, a simple effect of the format was noted on subjects' performances on the text-illustration schemas, $\chi^2(2, N = 576) = 28.71$, $P < 0.001$. An in-depth analysis reveals that the performances of the subjects in the separated group ($M = 4.47$, SD $= 2.69$) were significantly poorer than those in the integrated group ($M = 6.08$, SD $= 1.41$), $\beta = 1.56$, $z(564) = 4.03$, $P < 0.001$. Similarly, the performances of the subjects in the separated group ($M = 4.47$, SD $= 2.69$) were significantly poorer than those in the pop-up windows group ($M = 6.37$, SD $= 1.52$) on the same task, $\beta = 1.02$, $z(564) = 2.88$, $P < 0.01$. In contrast, no significant difference was observed between the performances of the integrated group ($M = 6.08$, SD $= 1.41$) and pop-up windows group ($M = 6.37$, SD $= 1.52$), $\beta = 0.54$, $z(564) = 1.32$, $P = 0.19$ (Table 3).

Completion of schemas

Initially, a simple effect of the format factor was observed on the schema completion scores, $\chi^2(2, N = 576) = 13.66$, $P < 0.001$. An in-depth analysis revealed that the schema completion performances of the integrated group ($M = 3.76$, SD $= 1.42$) were significantly poorer than those of the pop-up windows group ($M = 4.64$, SD $= 1.22$), $\beta = 0.66$, $z(564) = 2.18$, $P < 0.05$. The other comparisons of the information presentation formats revealed no significant difference (see Table 4).

Table 2. Mean performances on text-illustration paraphrase schemas and schema completion.

Format	Text-illustration paraphrase schemas		Schema completion		
	M	SD	*M*	SD	*n*
Separated	4.47	2.69	4.35	2.42	23
Integrated	6.08	1.41	3.48	2.61	25
Pop-up	6.37	1.52	4.95	1.94	24

Table 3. Summary of comparisons of formats for performances on text-illustration paraphrase schemas.

Comparisons	z value	Standard error z	β	P
Separated vs. integrated	4.03	0.38	1.56	<0.001
Separated vs. pop-up	2.88	0.35	1.02	<0.01
Integrated vs. pop-up	-1.32	0.40	-0.54	NS

Deviance: $\chi^2 = 0.83$ for 1 degree of freedom.

Table 4. Summary of comparisons of formats for schema completion performances.

Comparisons	z value	Standard error z	β	P
Separated vs. Integrated	0.71	0.29	0.21	NS
Separated vs. Pop-up	1.45	0.31	0.46	NS
Integrated vs. Pop-up	2.18	0.31	0.66	<0.05

Note: Deviance: $\chi^2 = 0.99$ for 1 degree of freedom.

To summarize the present results briefly, subjects working with either of the integrated formats obtained better performances in retention tests based on textual elements (paraphrases) than those who worked with the separated format. Similarly, the integrated groups were better at explicitly restoring the referential links between text and illustration (text-illustration paraphrase schemas). As far as global comprehension is concerned, the group that was working with pop-up windows recorded better performances on inferences compared with the other two groups. Finally, the performances in the retention test based on illustrated elements (completion of schemas) indicated that subjects working with the integrated text and illustration format performed worse than those in the separated and the pop-up windows groups.

Discussion

The present results are partially in accordance with our predictions. As expected, the spatial integration of the information facilitated the co-referencing of the text and illustrated elements. Consequently, it improved the quality of the mental representations generated on the basis of the documents. The performances of the subjects in the integrated and pop-up windows conditions were significantly better than those of the subjects in the separated condition on both the inference questions as well as on the text-illustration paraphrase schemas. Many works in the field of the cognitive load tend to explain the present effects as owed to a disappearance of the split attention effect. In our opinion, the benefit observed in the integrated formats could be explained mainly by an explicit restoration of referential links between text and illustration. Concretely, the integrated formats facilitate the information processing by explicitly connecting the textual elements to the corresponding illustrated elements. On the other hand, the separated format must have hindered the elaboration of mental representation, forcing the learner to use costly treatement aiming at inferring the links between text and illustration. This process of mapping could have led to several errors and could have been carried out at the cost of the elaboration of relevant mental representations.

Contrary to our expectations, the performances on questions relating to memorization of textual elements (paraphrases) seem to be affected by the spatial integration of informations. Basically, our results suggest that the performances of the separated group on the paraphrase-type questions were significantly poorer than those of the integrated and pop-up windows groups. This result runs counter to a number of conclusions formulated in the literature. Chandler and Sweller (1991), like Jamet (2000), have observed that the restoration of text-illustration co-referencing produces no improvement in performances on tasks that are not focused on this type of process. However, studies conducted by Mayer (1989) and Moreno and Mayer (1999) seem to contradict these observations. In both of these studies, the authors observed that the performances of learners in tasks requiring the free recall of information were better when they were confronted with formats favouring the spatial contiguity of the textual and illustrated information compared with conventional formats. At first glance, these observations appear to be compatible with those made in our study. However, they are unable to help explain our results given that tasks based on the free recall of information do not involve exactly the same processes as those mobilized by paraphrase-type questions. In order to explain the improvement in learners' performances with regard to the memorization of text elements, two hypotheses can nevertheless be called on. The first is based on the benefits of reconstructing the explicit relations between the text and the illustration. The presence of explicit referential links between the text and the illustration in the integrated and pop-up windows formats would have allowed the students to reduce their learning times and to devote more time to the memorization of the textual information. Our second explanatory hypothesis is based on studies conduced by both Kintsch and Schnotz. According to Kintsch *et al*. (1990), paraphrases can be used to test the relevance of the surface representation of the text involved in the elaboration of the text base. In other words, the higher performances on the paraphrases would seem to reflect a high-quality surface representation. The work conducted by Schnotz (2002) could help explain this improvement in the surface representation. In the model of the acquisition of illustrated documents, the learning of a text triggers the application of different types of processing that make it possible to arrive at a surface representation, a text base and then a mental model, respectively. The elaboration of this mental model then permits the triggering of various types of 'top-down' processing: model inspections on the text base, and reworking of the surface representation by the text base through the establishment of a correspondence between the semantic contents and the associated symbols. If the restoration of text-illustration co-referencing induced by the spatial integration of information improves the quality of the mental model through the implementation of 'top-down' processes, it also helps improve the surface representation and, consequently, subjects' performances in paraphrase tasks.

The results of our study do not simply reveal the benefit of the spatial integration of information on the establishment of co-references between text and illustration; they also point out an improvement of performances in the pop-up windows format compared with the integrated format which is in accord with our hypothesis

The pop-up windows format makes it possible to obtain better performances than are found with the integrated format in schema completion tasks. At first glance, this result seems to support the assumption of perceptual sailence of the illustration in the pop-up windows formats. According to Caro and Bétrancourt (2000), the spatial integration of text elements through the use of pop-up windows seems to help learners focus their attention on the illustration and consequently improves their ability to memorize illustrated information. However, this hypothesis seems unlikely as there is no significant variation in performances between the pop-up windows format, in which the illustrated information is effectively made salient, and the separated format in which the presence of the text prevents the illustration from becoming salient. A possible explanation of this result is the presence of a perceptual overload in the integrated format. Thus, the spatial proximity between text and illustration in the integrated format can induce a greater informative density on screen. This informative density might have impeded the processing of the illustration and led to poor performances in the tasks requiring the memorization of the illustrated elements. In contrast, this interference between the text and illustrated elements is less likely in the separated and pop-up windows formats as, in the first case, the text is physically separated from the illustration and, in the second, it is located within pop-up windows. Presently, other studies are being conducted to determine whether the perceptual overload has a real impact on the memorization of illustrated information.

Our study yields another important result pointing to the superiority in a learning perspective of the pop-up windows over the integrated format. Thus, the inference scores in the pop-up windows format were higher than those in the integrated format. This improvement in comprehension performance can be explained by the intervention of two explanatory factors. The first is associated with the disappearance of the perceptual overload in the pop-up windows format. As is the case for schema completion, the disappearance of this visual disruption in the pop-up windows format might have improved the relevance of the processing operation performed on the basis of the documents and might consequently have encouraged the elaboration of a high-quality mental model. The second explanatory factor seems to be associated with interactive processing induced by the pop-up windows. Many studies have attempted to evaluate the effects of interaction with the environment on individuals' learning performances. Bodemer and Faust (2006) have shown that the active reconstruction of documents by means of a 'drag and drop' process makes it possible to improve the quality of the mental representations generated from a document. In our case, the use of an interactive environment using pop-up windows might have helped learners' investment in task fulfilment, thus eventually resulting in the development of mental representations of a higher quality than those generated in an equivalent, but noninteractive environment. Currently, it seems difficult to explain the origin of these benefits, and a number of studies will be necessary to distinguish the genuine contributions of interaction with the environment from the disappearance of the perceptual overload in the development of relevant mental representations.

Overall, the results observed using these educational documents are in line with those observed by Bétrancourt and Bisseret (1998). Indeed, we observed a beneficial effect of the spatial integration of information on the relevance of the mental model generated on the basis of illustrated documents. However, our study of educational documents goes beyond this by revealing the beneficial effects of the pop-up windows format compared with the integrated format. This last observation raises many questions. One of the most essential concerns the explanatory factor that sparks off this performance improvement with pop-up windows. It is actually difficult to distinguish the impact of environment interactivity from the one of pecerptual overload. Another question deals with the generalization of these results. The current observations apply solely to the domain of explicit learning and it would therefore be necessary to verify whether the beneficial effect of pop-up windows still prevails in the domain of information seeking.

References

Bétrancourt M. & Bisseret A. (1998) Integrating textual and pictorial information via pop-windows: an experimental study. *Behavior and Information Technology* **17**, 263–273.

Bétrancourt M. & Caro S. (1998) Intégrer des informations en escamots dans les textes techniques: quels effets sur les processus cognitifs ? In *Hypertextes et Hypermédias, Concevoir et utiliser les Hypermédias: Approches Cognitives et Ergonomiques* (eds A. Tricot & J.F. Rouet), pp. 157–173. Hermès, Paris.

Bodemer D. & Faust U. (2006) External and mental referencing of multiple representations. *Computers in Human Behavior* **22**, 27–42.

Bodemer D., Ploetzner R., Feuerlein I. & Spada H. (2004) The active integration of information during learning with dynamic and interactive visualisations. *Learning and Instruction* **14**, 325–341.

Caro S. & Bétrancourt M. (2000) Ergonomie des documents numériques. In *Traité Informatique*, **H7 220**. Techniques pour l'Ingénieur (TPI), Paris.

Chandler P. & Sweller J. (1991) Cognitive load theory and the format of instruction. *Cognition and Instruction* **8**, 293–332.

Chandler P. & Sweller J. (1992) The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology* **62**, 233–246.

Chandler P. & Sweller J. (1996) Cognitive load while learning to use a computer program. *Applied Cognitive Psychology* **10**, 151–170.

Glenberg A.M. & Langston W.E. (1992) Comprehension of illustrated text: pictures help to build mental models. *Journal of Memory and Language* **31**, 129–151.

Gyselinck V. & Tardieu H. (1999) The role of illustrations in text comprehension: what, when, for whom, and why? In *The Construction of Mental Representations During Reading* (eds S.R. Goldman & H. van Oostendorp), pp. 195–218. Lawrence Erlbaum Associates, New Jersey.

Gyselinck V., Ehrlich M.F., Cornoldi C., de Beni R. & Dubois V. (2000) Visuospatial working memory in learning from multimedia systems. *Journal of Computer Assisted Learning* **16**, 166–176.

Hannus M. & Hyönä J. (1999) Utilization of illustrations during learning of science textbook passages among low- and high-ability children. *Contemporary Educational Psychology* **24**, 95–123.

Hegarty M. & Just M.A. (1993) Constructing mental models of machines from text and diagrams. *Journal of Memory and Language* **32**, 717–742.

Jamet E. (2000) L'intégration spatiale d'éléments textuels et illustratifs améliore-t-elle la performance? *Revue d'intelligence artificielle: Les Interactions Homme-Système: perspectives et recherches psycho-ergonomiques* **14**, 167–188.

Johnson-Laird P.N. (1983) *Mental Models: Toward a Cognitive Science of Language, Inference, and Consciousness*. Harvard University Press, Cambridge.

Kintsch W. (1998) *Comprehension: A Paradigm for Cognition*. Cambridge University Press, Cambridge UK.

Kintsch W., Welsch D., Schmalhofer F. & Zimny S. (1990) Sentence memory: a theoretical analysis. *Journal of Memory and Language* **29**, 133–159.

Levie W.H. & Lentz R. (1982) Effects of text illustrations: a review of research. *Educational Communication and Technology Journal* **30**, 195–232.

Mayer R.E. (1989) Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology* **81**, 240–246.

Mayer R.E. (1997) Multimedia learning: are we asking the right questions? *Educational psychologist* **32**, 1–19.

Mayer R.E. (2001) *Multimedia Learning*. Cambridge University Press, Cambridge, UK.

Mayer R.E. & Gallini J. (1990) When is an illustration worth ten thousand words? *Journal of Educational Psychology* **82**, 715–726.

Mayer R.E., Steinhoff K., Bower G.H. & Mars R. (1995) A generative theory of textbook design: using annoted Illustrations to foster meaningful learning of science text. *Educational Technology Research and Development* **43**, 31–44.

McCullagh P. & Nelder J.A. (1983) *Generalized Linear Models*. Chapman & Hall, London, UK.

Moreno R. & Mayer R.E. (1999) Cognitive principles of multimedia learning: the role of modality and contiguity. *Journal of Educational Psychology* **91**, 358–368.

Schnotz W. (2002) Commentary – Towards an integrated view of learning from text and visual displays. *Educational Psychology Review* **14**, 101–120.

Schnotz W., Böckheler J. & Grzondziel H. (1999) Individual and co-operative learning with interactive animated pictures. *European Journal of Psychology of Education* **14**, 245–265.

Sweller J. (1999) *Instructional Design in Technical Areas*. ACER Press, Melbourne.

Sweller J. & Chandler P. (1991) Evidence for cognitive load theory. *Cognition & Instruction* **8**, 351–352.

Sweller J., Chandler P., Tierney P. & Cooper M. (1990) Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General* **119**, 176–192.