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Authors
Verbrugge, Sara
Stas, Aurélie
Jaspaert, Koen

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Text, images and diagrams as information providers

Sara Verbrugge (Sara.Verbrugge@kuleuven.be)
Aurélie Stas (aureliestas8@hotmail.com)
Koen Jaspaert (Koen.Jaspaert@arts.kuleuven.be)
Department of Linguistics, University of Leuven, Blijde Inkomststraat 21, 3000 Leuven, Belgium

Abstract

We studied the effect of adjunct displays on recall in an expository text (based on McCrudden, Schraw, Lehman, & Poliquin, 2007) in order to find out which means of display aided pupils in the last years of secondary school to recall information. We included four conditions in the experiment: text only, text and causal diagram, text and images and causal diagram only. Participants were checked for their recall of main ideas and causal sequences. Recall for main ideas did not vary significantly across conditions. Contrary to McCrudden et al. (2007), our results for the causal sequences revealed that participants who studied a causal diagram only could recall more steps from causal sequences than participants in any of the other conditions. We will interpret the findings in the light of the literature on redundancy effects, dual coding theory, and the causal explication hypothesis.

Keywords: Causal diagram; Text comprehension; Causal relationships; Visual/spatial display

Introduction

We set up an experiment studying the benefits of adding causal diagrams and illustrations to expository texts for recall of information. We will discuss the use of adjunct displays (i.e. visual representations that complement text with the purpose of making the information present more easily understandable and better recalled) in previous research. After that, we will go into more detail on the specific advantages of causal diagrams for text interpretation.

Benefits of adjunct displays

Adding so called "adjunct displays" i.e. powerpoint presentations, images, causal diagrams, etc. to a spoken or written text does not always entail the expected benefits for the reader or listener. When these kinds of adjunct displays are added to text, they restate the same information of the text in a new form (such as causal diagrams) or add new chunks of information (such as images). The audience's preexisting knowledge about the topic and the amount of overlap between the two sources of information are two variables that need to be considered. When taking these nuances into account, adding visual displays can promote recall, provided they are implemented in the right way.

Vekiri (2002) presented an overview of the advantages of different graphical displays for recall and suggested that graphics make a valuable contribution to learning only when readers can interpret and integrate the information without extra processing demands. The effects of adding graphics are mediated by variables such as the participants' pre-existing knowledge about the subject of study and visuospatial ability. Also, graphic displays need to be adjusted to task demands. E.g. when an important part of text comprehension is understanding cause-effect relations, the diagram should explicate these relations and their interactions (Mayer & Gallini, 1990). When graphs are used in a right way, they improve understanding. When this is not the case, they often interfere with learning because they impose extra processing demands reducing working memory capacity for learning activities.

Because of the way diagrams organize text and explicate relations, they make it easier to draw inferences about the relations that are present (Robinson & Kiewra, 1995). Precisely because links are provided between information bits, relations that might otherwise have remained implicit are now more easily computed (Larkin & Simon, 1987). See also the causal explication hypothesis (Graesser & Bertus, 1998; McCrudden et al., 2007, p. 372): adding causal diagrams improves text comprehension because "they provide an explicit visual representation of a text's causal structure that helps the reader understand the text's causal structure". Analyzing causal relationships between text fragments is cognitively demanding. Presenting a causal diagram can help readers to construct a mental model of the text and hence leave more room for inference drawing and consequently a deeper comprehension of the text.

McCrudden et al. (2009, p. 81) present four reasons why the use of adjunct displays boosts understanding of causal relationships. First, a saliency issue: the relevant causal steps are brought to the fore. Their second reason refers to the reduction of cognitive effort. Third, a holistic understanding of the causal structure of the text is more easily achieved. A last reason is concerned with spreading the information via different channels: "it is possible that an adjunct display distributes the information across verbal and spatial working memory stores, functionally increasing its capacity" (McCrudden et al., 2009, p. 81).

Apart from causal diagrams, images are also often added to text. The visual "argument hypothesis" and "picture superiority effect" state that adding images is effective because they are more easily processed than text. In that respect, reference is often made to the "dual coding theory" (Paivio, 1990) that attributes these benefits to the assumption that there are two different codes for visual information (stemming from pictures or words). The dual coding theory postulates that there are two distinct cognitive systems for information processing and retrieval. "Imagens" stores nonverbal information in mental images, whereas "logogens" stores verbal information in word-like codes (see also Vekiri, 2002). The dual coding theory had been called into question by Johnson-Laird (1998) claiming that information from both verbal and image cues is represented in a single amodal form (see also Vekiri, 2002). These challenges have received recent support from neurological studies. Specifically, recent neural evidence has shown (Shinkareva, Malave, Mason, Mitchell, & Just, 2011) that patterns of brain activity when thinking about concrete objects are independent of the stimulus presentation format (i.e. words or pictures). Neural states could be identified that are common to pictorial and verbal input referring to objects categories. Not only could they find this effect within participants, but regions of brain activity could also be predicted across participants. "The category of a noun that a person reads or thinks about can be identified solely on the basis of activation patterns obtained from other individuals" (Shinkareva et al. 2011, p. 2422). This evidence at least suggests that the dual coding theory and the picture superiority effect need rethinking.

Influence of causal diagrams on comprehension

In this section, we address the question whether causal diagrams bring specific advantages for text interpretation. Several studies with undergraduate students have revealed the beneficial nature of adding causal diagrams to texts.

McCrudden et al. (2007) present participants with texts accompanied or unaccompanied by a causal diagram (i.e. a type of visual display that explicitly represents cause-effect relationships, McCrudden 2007, p. 367) summarizing the main ideas and causal sequences of the text. Their results showed that participants who studied both text and causal diagram understood better the five causal sequences in the text. In a second experiment, in which participants studied either the text or the causal diagram, no differences could be found for recall of main ideas or causal sequences between the two conditions. They conclude that causal diagrams are not merely redundant with text.

McCrudden, Schraw, and Lehman (2009) set up two experiments in which participants read a text, either followed by the task to study a causal diagram, to study a list, or to reread the text. After that, participants were asked a range of questions focusing on the steps in the causal sequences and the transitive relationships between causes and effects. Participants in the reread condition performed worse than participants in the other conditions. On the basis of similar results in the two experiments they conducted, McCrudden, Schraw, and Lehman (2009, p. 80) conclude that explicating the steps in a causal chain improves comprehension of the text and learning of causal relationships.

In another study McCrudden, Magliano and Schraw (2011) investigated the online reading processes of participants while they were reading a text or studying a diagram. In their first experiment participants either studied the causal diagram before reading the text or did not study the causal diagram before reading the text. Participants who studied a diagram before reading the text had faster overall reading times than participants who did not. Moreover, participants in the diagram condition recalled more information than participants in the no-diagram condition. In a second experiment, participants in the no-diagram condition had to read the text twice in order to make the experiment similar for the two groups, and in order to preclude the fact that the effect from the first experiment was due to the repetition of content (2011, p. 78). Again they conclude that "exposure to the diagram had a beneficial effect on comprehension over and above simple repetition" (2011, p. 81). Reading time data showed that reading times of the text of participants who first studied a causal diagram were longer than those of participants who simply reread the text. After that they compared text reading times of participants in the diagram condition with text reading times of participants (of the first reading of the text) in the reread condition. No differences could be found between them. In a third experiment participants were asked to "think aloud" while studying the texts or diagrams. It was shown that presence of a diagram improved the participants' recognition of causal relations.

Experiment: the contributions of text, images and causal diagrams for recall

We investigate the effects of images and visual displays on recall of information from expository science texts. As in McCrudden et al. (2007) we included conditions with text only, text and diagram, and diagram only. The diagram consists of key terms of the text; relations and sequences are expressed by means of arrows.

Our study diverged from the one by McCrudden et al. (2007) in five important respects. First, we added a condition with text and images. We wanted to find out whether visual displays aided recall of ideas and causal sequences and if they did, which kind of visual display was most beneficial for a thorough understanding and recall. Do causal diagrams entail a bigger advantage because they explicate causal relations? Or do images contribute equally to the comprehension process because they visually represent the content? Second, we did not include a reread condition in our experiment because we think this condition is not straightforwardly comparable to the other conditions. Participants who were asked to reread the text probably invested less effort than participants who received slightly new materials summarizing the main ideas of the text they had just read. In our opinion, rereading a text that is exactly the same as the one you have just read is bound to go a lot faster. Third, we opted for a direct comparison between all four conditions in one experiment. Fourth, participants were given less time to study the causal diagram than in the study by McCrudden et al. (2007). Less information needs to be processed and we wanted to find out whether similar results could be achieved with less studying time. Fifth, we decided to recruit pupils from secondary schools because the lion's share of research has been carried out with university students and elementary school children, and little attention has been paid to pupils in the last years of secondary school (see also: Mason, Tornatora, & Pluchino, 2013). Because pupils in this age category are studying many different subjects, are getting acquainted with studying larger chunks of information and need to make important decisions about their future study and career orientations, they are a very interesting group to look into in more detail.

In the experiment participants were allocated to one of four conditions: study a text combined with images, a text combined with a causal diagram, only the causal diagram, or only the text. Participants were tested for their recall of main ideas and for their recall of steps from a causal chain. As in McCrudden et al. (2007) we expect no differences for recall of the main ideas, because their understanding does not rely on participants' ability to link information. We do expect differences for recall of causal sequences because these require participants to build a mental model of the text with causal links, which burdens cognitive resources (Graesser & Bertus, 1998). If the participants in the text only condition outperform the other conditions, this provides evidence that accompanying materials are redundant. If on the other hand, participants in the condition of text accompanied by causal diagram or causal diagram alone outperform the other conditions, it provides evidence in favour of the causal explication hypothesis: explicating causal relations in a diagram helps processing. If the condition of text combined with images is better than the rest, this supports the visual argument hypothesis.

On the basis of the literature, we hypothesize that participants will perform better in the conditions where text is accompanied by a visual aid, be it a causal diagram or an image.

Method

Participants 91 pupils from the fifth and sixth grade secondary education (mean age=17.05, *SD*=0.85) took part in the experiment. The participants' mother tongue was Dutch.

Design The materials were manipulated between subjects. Participants were randomly attributed to one of four conditions: text and images, text and diagram, text only, or diagram only.

Materials The materials varied in the four conditions. Basis in all cases was an explanatory scientific text about space travel. In the 'text only' condition participants read a text of 1171 words. The text was taken from McCrudden et al. (2007)[1] and translated into Dutch. A few minor adaptations were made in order to make the text more easily readable in Dutch. In the 'text and images' condition the same text was used, but now accompanied by six images. Every image highlighted a particular step from one of the five causal sequences. Three images illustrated a step from the causal sequence (osteoporosis, an excess of bodily fluids in the upper regions of the body, contradictory signals in the brain about the body's orientation). The other three images illustrated a consequence or danger of the causal sequence (kidney stones, muscle loss, heart shrink). In the 'text and diagram' condition, the text was accompanied by a causal diagram. Text and diagram were presented simultaneously. The causal diagram was taken from McCrudden et al. (2007) and translated into Dutch. The causal diagram consists of five cause-consequence relations originating from a common cause: lack of gravity during space travel. In the 'diagram only' condition participants only studied the diagram. In the 'text and diagram' condition and 'diagram only' condition, the materials were preceded by a few lines instructing the participants how to read and interpret the diagram.

Test materials consisted of a questionnaire consisting of two parts. The first part contained three questions. The first asked about participants' prior knowledge about space travel (1= knew nothing – 6 = already knew everything). The second question asked participants to write a short text about their willingness to become a space traveler after having read about the dangers of space traveling. This question was inserted in order to create a time buffer between reading the text and answering recall questions. The third question enquired about the "main ideas": participants were asked to name parts of the body that were affected by space travel, and the associated risks (e.g. lack of gravity influenced bone structure, which augmented the risk of kidney stones). The second part of the questionnaire focused on the causal sequences. A particular risk was given (e.g. space travel may cause kidney stones) and participants were asked to list as many causal steps as they could remember. They were invited to explain why the risk existed and to name as many causes and consequences as possible.

Procedure The experiment was conducted in a large study room. Participants in the 'text only', 'text and images', and 'text and diagram' conditions were given 8 minutes to study the materials, participants in the 'diagram only' condition were given 4 minutes to study the materials. (Time needed was determined on the basis of a small pretest.) The 8 minutes group was told after four minutes that four minutes remained. All groups were informed one minute before the end that one minute remained. The materials were collected

[1] "The text was a two-page, 1385-word passage entitled Space Travel (see Appendix A) that described effects of space travel on the human body at an introductory level. It was adapted from several sources including two Web-pages from an educational Web site for NASA: When Space Makes You Dizzy (Phillips & Hullander, 2002) and Mixed up in Space (Phillips & Hullander, 2001), and one Web-page from an educational Web site for the National Space Biomedical Research Institute: Human Physiology in Space (Lujan & White, 2002)." (McCrudden et al., 2007, p. 373)

and the first part of the questionnaires was handed out. When participants had finished the first part of the questionnaire, they raised their hands, handed in the first part and received the second part of the questionnaire. No time limits were imposed to fill in the questionnaires. The experiment took the participants approximately 45 minutes.

Results

Preliminary questions: On the question how well acquainted participants were with the subject of space travel on a scale from 1 (=knew nothing) to 6 (=knew everything already), an average of 2.3 was reached (23 participants chose 1 on the scale, 34 chose 2, 19 chose 3, 12 chose 4, 3 chose 5, none chose 6). Correlations were checked between overall recall of main ideas and prior knowledge and between overall recall of causal sequences and prior knowledge but no significant correlations were found.

Main ideas: An ANOVA was conducted with text type (causal diagram only – text only – text and diagram – text and images) as the independent variable and main ideas as the dependent variable. No main effect of text type could be found: $F(3, 87)=.739$, $p=.53$. Recall of main ideas did not differ significantly whether participants read the 'text only', 'text and diagram', 'text and images' or the 'causal diagram only'.

Causal sequences: As for recall of the causal sequences, we conducted an ANOVA with text type as between subjects variable and causal sequence as within subjects variable (repeated measures). To allow for comparisons across causal steps, scores were converted to proportions. I.e. per causal sequence, the number of causal steps remembered was divided by the total number of causal steps for that particular sequence.

There was a main effect of text type $F(3, 87)=3.93$, $p=.011$. Causal diagram ($M=0.52$) led to greater recall than any of the other text types (text only $M=0.34$ – text and diagram $M=0.39$ – text and images $M=0.33$). Planned comparisons revealed that 'diagram only' differed significantly from 'text and diagram' $F(1, 87)=4.91$, $p=.0015$, which was the second best condition for recall.

There was a main effect of specific topic of the causal sequences: $F(4, 348)=18.80$, $p=.00001$. Planned comparisons revealed that the causal sequence of 'muscle loss' was significantly more recalled than the other four causal sequences ('muscle loss' $M=0.57$ - kidney stones $M=0.43$; $F(1, 87)=10.66$, $p=.002$). No difference was found between the causal sequence 'kidney stones' and 'motion-sickness' ($M=0.42$), but these two causal sequences were better recalled than the causal sequence 'infections' (infections $M=0.31$ - kidney stones; $F(1, 87)=4.61$, $p=.035$), which was in turn more recalled than the causal sequence about 'heart shrink' (heart shrink $M= 0.25$ – infections $F(1, 87)=3.97$, $p=.049$).

The interaction between text type and causal sequence almost reached significance level: $F(12, 348)=1.66$, $p=.07$. The causal sequence that was easiest to remember (muscle loss) did not differ between the different text types. For the more difficult causal sequences, planned comparisons revealed that the participants in the "diagram only" condition always scored best (motion-sickness $F(1,87)=6.96$, $p=.009$; kidney stones $F(1,87)=9.32$, $p=.003$ infections $F(1,87)=8.25$, $p=.005$, and heart shrink $F(1,87)=7.59$, $p=.007$).

Discussion

As in McCrudden et al. (2007) no differences were found between the groups for recall of the main ideas.

The results for the causal sequences show that participants had higher recall rates when they studied a causal diagram only than any of the other types of materials (text only – text and diagram – text and images). No differences were found between the other conditions. Moreover, participants in the 'diagram only' condition only had four minutes to study the diagram, whereas the participants in the other conditions could study the materials for eight minutes. The fact that participants were able to achieve better comprehension in a shorter period of time, is surprising. This result runs counter to the results obtained in McCrudden et al. (2007) where no differences in recall of causal sequences between diagram and text could be found.

A straightforward explanation is the fact that the diagram only contained information that was relevant for the questions participants would receive (cf. the saliency issue discussed in the introduction). The other conditions with text also contained secondary information. A more in-depth explanation for these results might reside in the fact that participants need to invest more processing effort in understanding the diagram and this leads to deeper processing and hence a better retention of the studied materials in the brain. Ainsworth and Loizou (2003) and Moore and Scevak (1997) show that students make more inferences in diagrams than in running text. McCrudden, Magliano, and Schraw (2011) show that studying a diagram led to higher recall of information compared to text reading.

This experiment provides evidence that studying a diagram leads to a better retention in memory. When participants study texts, they may opt for the easy way out: the text reads smoothly, deep processing is not necessary for superficial text comprehension. Additional evidence for this claim can be found in the fact that, similar to the results of McCrudden et al. (2007), the more complex the causal sequence, the better participants could recall the causal sequences when they had studied a diagram compared to the other conditions. Difficult causal sequences may not have been understood profoundly enough in the text condition, whereas the diagram condition made sure the more difficult causal sequences were studied thoroughly. This fits in with the finding by Cromley et al. (2010, p. 69) that "students used a significantly higher proportion of inferences and high-level strategies and a significantly lower proportion of low-level strategies in diagrams than in text. (…) diagrams seemed to promote more high-level, integrative activity and seemed to discourage low-level superficial strategies."

An explanation why the 'text and diagram' condition did not have higher recall rates than the 'text only' condition, is to be found in the fact that students often skip diagrams or skim only parts of the diagram (see e.g. Schmidt-Weigand et al., 2010). Schmidt-Weigand et al. (2010) also showed that the time participants took to inspect visualizations of the text was considerably lower than the time participants took to read the text. Participants might find the information in the text sufficient and find the diagrams superfluous. When their expectations of relevance were met, they did not take the effort to study the diagrams in detail. This could be overcome in future research by presenting the diagram before the text.

Another surprising finding is that our results fail to support the so called "picture superiority effect" since the condition in which participants studied text and images had the lowest averages of all conditions (but not significantly lower than text only and text and diagram). It has been suggested that when words are processed meaningfully, memory for them may be comparable to that of pictures (Weldon & Coyote, 1996, p. 671). Processing of information (words, pictures, …) is optimized according to task requirements (Job & Tenconi, 2002). Once that purpose is defined, "the processing of information seems to proceed to levels that satisfy the task requirements" (Miller, 2011, p. 719). So in our experiment, adding pictures did not lead to better recall because the information present in the text was sufficient to the participants. Adding pictures did not entail any additional benefits. Apparently participants thought that the information was processed satisfactorily for the current purposes. While Levin & Mayer, 1993 and Marcus et al., 1996 (as cited in Pike et al. 2010) provided evidence that the use of illustrations reduces the demands on working memory and hence leaves more resources for higher order processing of the text, no evidence for this could be found in our results.

General Discussion

Here we will situate our results with regard to the causal explication, verbal redundancy, and picture superiority hypothesis. We will also discuss the implications for devising course materials.

Causal explication hypothesis

McCrudden et al. (2007) provided evidence in favour of the causal explication hypothesis, when text and causal diagram were presented together, because participants in the condition text and causal diagram outperformed the ones in the text only condition. On the basis of our results, we can say that our results tilt toward a redundancy effect when two sources of information are presented together. Even though it is claimed in McCrudden et al. (2007) that causal diagrams are not merely redundant with texts, this seems to be the case in our study. When adding a causal diagram to text, recall rates drop to levels similar to those of text only. This may be due to the fact that participants only had a look at the diagrams after having already processed the text and hence devoted less attention to it than when they first would have had a look at the causal diagram instead of vice versa.

However, when a causal diagram is presented on its own, recall for causal sequences improves. These results underpin the causal explication hypothesis. When implicit causal relations are made explicit in a causal diagram, recall significantly improves. Whether the effect is due to the fact that only the relevant information for the recall questions was summarized in the causal diagrams or whether it is actually due to their structure or both factors combined, will have to be left unresolved for the time being. However, there can be little doubt as to the role causal diagrams play in alleviating the strains put on our cognitive capacity. The resources made available in this way can then be devoted to storing the information and the links between bits of information more firmly in memory.

Verbal redundancy

The effect of redundant information has been studied on various levels. Many studies have been conducted investigating "verbal redundancy". When similar information is simultaneously given via different channels (i.e. spoken and written information), comprehension and recall are not necessarily better than when the information is only given in one form. These studies have often been carried out in multimedia environments. The overall conclusion is that when redundant information is given, learning becomes impaired. Rey and Buchwald (2011), Sweller (2005a, 2005b) have shown that offering redundant material often interferes with learning rather than facilitating it (see Sweller, 2005b, p. 159). This redundancy effect is attributed to the fact that working memory capacity is burdened excessively with integrating identical information received via different sources. The results of the experiment are in accordance with the aforementioned studies. When the information is twice presented (causal diagram and text, or text and pictures) learning does not improve compared to the text only condition. So the fact that the information is given in two versions does not hinder learning but neither does it improve learning.

Picture superiority

As we have argued in the discussion, we fail to find evidence for the picture superiority effect. When pictures are added to text, recall does not improve. The positive effect of a causal diagram cannot be interpreted in terms of picture superiority, because causal diagrams are not pictures, but they are small summaries of causal information in the text.

Suggestions for study materials

In conclusion, we can say that causal diagrams turn out to be a very convenient study aid, when a deeper understanding of relations is aimed for. It is even the case that causal diagrams appear to be the principal matter to study for students instead of texts when recall of causal relations is at stake. Participants who studied the causal diagram alone, outperformed the participants in any of the other conditions. So, we can recommend students to draw causal diagrams of the materials they have to study and authors of school and college books to add causal diagrams whenever possible summarizing the main ideas and the relations between them. Making the structure of the text more insightful is a vital characteristic of causal diagrams.

In short, our findings hints towards the need to elucidate course material with diagrams in order to boost memory.

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