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Multimedia instructions and cognitive load theory: Effects of modality and cueing

Huib K. Tabbers*, Rob L. Martens and Jeroen J. G. van Merriënboer

Educational Technology Expertise Centre, Open University of The Netherlands

Background. Recent research on the influence of presentation format on the effectiveness of multimedia instructions has yielded some interesting results. According to cognitive load theory (Sweller, Van Merriënboer, & Paas, 1998) and Mayer's theory of multimedia learning (Mayer, 2001), replacing visual text with spoken text (*the modality effect*) and adding visual cues relating elements of a picture to the text (*the cueing effect*) both increase the effectiveness of multimedia instructions in terms of better learning results or less mental effort spent.

Aims. The aim of this study was to test the generalisability of the modality and cueing effect in a classroom setting.

Sample. The participants were 111 second-year students from the Department of Education at the University of Gent in Belgium (age between 19 and 25 years).

Method. The participants studied a web-based multimedia lesson on instructional design for about one hour. Afterwards they completed a retention and a transfer test. During both the instruction and the tests, self-report measures of mental effort were administered.

Results. Adding visual cues to the pictures resulted in higher retention scores, while replacing visual text with spoken text resulted in lower retention and transfer scores.

Conclusions. Only a weak cueing effect and even a reverse modality effect have been found, indicating that both effects do not easily generalise to non-laboratory settings. A possible explanation for the reversed modality effect is that the multimedia instructions in this study were learner-paced, as opposed to the system-paced instructions used in earlier research.

** Correspondence should be addressed to Huib Tabbers, Communication & Cognition, Faculty of Arts, Tilburg University, Warandelaan 2, PO Box 90153, 5000 LE Tilburg, The Netherlands (e-mail: tabbers@uvt.nl).*

The use of multimedia computers in education has led to the development of all sorts of instructional material in which verbal and non-verbal presentation modes are combined. Unfortunately, educational research has not yet identified how to design effective multimedia instructions. However, two recent lines of research that have yielded some promising results are the work on cognitive load theory by Sweller and others (for an overview, see Sweller, 1999) and the experiments on multimedia learning carried out by Mayer and colleagues (for an overview, see Mayer, 2001). Both researchers base their instructional design principles on human cognitive architecture and the way in which the multimedia material is processed. In his theory of multimedia learning, Mayer (2001) describes how the learner builds mental representations of multimedia instructions. One important step in this process is the integration of both verbal and visual information in working memory. For example, when instructions consist of a picture and an explanatory text, the learner has to switch back and forth between the two to integrate them mentally. This process is cognitively demanding, at the expense of mental resources that could otherwise be allocated to the learning process.

Cognitive load theory calls the unnecessary memory load caused by the presentation format of instructions *extraneous* load (Sweller, Van Merriënboer, & Paas, 1998). Changing the presentation format can lower this extraneous load and increase the effectiveness of instructions. For example, Sweller and others have shown that the physical integration of verbal and visual information resulted in improved test scores (Chandler & Sweller, 1991, 1992; Kalyuga, Chandler, & Sweller, 1998; Sweller, Chandler, Tierney, & Cooper, 1990; Tarmizi & Sweller, 1988). When a textbox is placed right next to the part of the picture the text is referring to, the need to mentally integrate text and picture is reduced, which lowers the extraneous load and facilitates the learning process. Sweller *et al.* (1998) call this the *split-attention effect*. A similar effect has been demonstrated by Mayer and colleagues in a series of experiments in which they showed that multimedia instructions were more effective when verbal and visual information were presented close to each other rather than spatially separated (Mayer, 1989; Mayer, Steinhoff, Bower, & Mars, 1995; Moreno & Mayer, 1999). Mayer (2001) calls it the *contiguity principle*.

A more recent finding is that multimedia instructions can be more effective when the verbal information is presented auditorily instead of visually. This is called the *modality effect* (Sweller *et al.*, 1998) or *modality principle* (Mayer, 2001). A number of experiments have demonstrated that replacing written or on-screen text with spoken text improved the learning process in different ways: lower mental effort during instruction and higher test scores (Kalyuga, Chandler, & Sweller, 1999, 2000; Tindall-Ford, Chandler, & Sweller, 1997), less time on subsequent problem solving (Jeung, Chandler, & Sweller, 1997; Mousavi, Low, & Sweller, 1995), and improved scores on retention, transfer and matching tests (Mayer & Moreno, 1998; Moreno & Mayer, 1999). The authors explain these diverse results by referring to the working memory model of Baddeley (1992). In this model, working memory has two modality-specific slave systems, one for visual and spatial information and one for acoustic information. When information is presented in two sensory modalities (visual and auditory) rather than one, both slave systems are addressed and total working memory capacity is used more efficiently. So, relative to the available resources, the extraneous load of the multimedia instructions is reduced.

Both strategies, physically integrating text and picture and replacing written or on-screen text with spoken text, reduce the extraneous load of multimedia instructions and thus increase the effectiveness of the learning process. In both cases, this reduction in cognitive load can partly be accounted for by the reduction in the amount of visual search needed to integrate text and picture. The effect of reducing visual search has been explicitly demonstrated in two studies by Jeung *et al.* (1997) and by Kalyuga *et al.* (1999). Jeung *et al.* showed that replacing visual text with spoken text does not always improve the effectiveness of multimedia instructions, especially when pictures with a high visual complexity are used. Only when they added to the pictures in the bimodal condition visual cues that related the right elements in the picture to the accompanying spoken text, did they recover the modality effect in terms of shorter time on subsequent problem solving. Kalyuga *et al.* found the same *cueing effect* with visual-only instructions. In one experiment they used colour coding to link on-screen text with corresponding parts of the picture. This resulted in better test scores when compared to instructions without any visual cues.

In the studies in which the modality effect was demonstrated, the authors claimed that the reduction in extraneous load of the multimedia instructions resulted from a more efficient use of the available memory resources. However, the results obtained in the experiments could also largely be explained in terms of a reduction in visual search. For example, Jeung *et al.* (1997), Mousavi *et al.* (1995) and Tindall-Ford *et al.* (1997) used visual-only instructions in which *all* explanatory text was printed next to the diagram and compared it to instructions in which the students saw only the picture and could listen to the explanation. That means that they not only replaced visual text with spoken text but also drastically reduced the visual search necessary to link the right parts of the text with the right parts of the diagram. So in their experiments, the difference in effectiveness between bimodal and visual-only instructions could be largely attributed to the difference in visual complexity. Mayer and Moreno (1998; Moreno & Mayer, 1999) and Kalyuga *et al.* (1999, 2000) on the other hand cut their explanatory texts in smaller pieces, reducing the visual search to a minimum. However, in their experiments the instructions were presented as system-paced animations. The time a student could study a picture and its accompanying texts was determined by the pace of the narration in the bimodal condition. The learners in the bimodal condition could use this limited period of time more effectively because they could look at the picture and listen to the text at the same time, while the learners in the visual-only condition had to spend part of their time in a process of visual search as they had to skip back and forth between text and picture. To adjust for this unwanted effect, Moreno and Mayer (1999) in one experiment used instructions in which the animation and the accompanying text were presented sequentially instead of simultaneously. Despite the temporal detachment of text and picture, bimodal instructions still proved to be superior to visual-only instructions. According to the authors, this result showed that the modality effect is at least partly the result of a more efficient use of working memory resources.

Based on the results obtained in their empirical work, both Sweller and Mayer claim that multimedia instructions will be more effective when the verbal information is presented auditorily instead of visually. However, some reservations can be made on the generalisability of their findings. First, the studies conducted thus far were all tightly controlled laboratory experiments. Moreover, almost all multimedia instructions used in the above mentioned studies taught subjects from technical domains like geometry (Jeung *et al.*, 1997; Mousavi *et al.*, 1995), scientific explanations of how lightning develops (Mayer & Moreno, 1998; Moreno & Mayer, 1999), electrical engineering (Kalyuga *et al.*, 1999; Tindall-Ford *et al.*, 1997), and reading a technical diagram

(Kalyuga *et al.*, 2000). Finally, students had only a few minutes to study the instructional material, and the maximum study time was always based on the time needed to hear the narration.

The aim of the present study was to test the generalisability of the modality effect. Therefore, the set-up of the current experiment differed from earlier experiments in a number of ways. First, the multimedia material discussed a non-technical subject matter, namely instructional design. Furthermore, the instruction time was more than an hour, and the instructions were learner-paced instead of system-paced. Finally, the experiment took place in an ecologically more valid classroom setting. To see if a reduction in visual search could partly account for the modality effect, the cueing effect was included in the study as well.

Cognitive load theory would predict that presenting texts accompanying a picture as spoken text will decrease the extraneous load and increase the effectiveness of the instructions (the modality effect), and that adding visual cues to a picture that relate the relevant elements of the picture to the text will prevent visual search and also increase the effectiveness of the instructions (the cueing effect). To study both the modality and the cueing effect, four different versions of the multimedia instructions were created, differing in the modality of text and the use of visual cues. To determine the effectiveness of the instructions, we looked at the extent to which students could recall elements of the instructional design model that had been studied in a retention test, and at the extent to which they could apply the model in a new situation in a transfer test. Furthermore, to draw conclusions not only about the effectiveness but also about the efficiency of the different presentation modes, we used a self-report measure of mental effort during both the instructions and the tests, and recorded the total time spent on the instructions.

Method

Participants

The participants were 111 second-year students from the Department of Education of the University of Gent in Belgium (age between 19 and 25 years; 16 males and 95 females). Originally, 114 students participated, but the results of three students were removed from the sample because they had not completed the instructions in the maximum time. The experiment was part of a regular course on instructional design, but at the time of the experiment the students had not yet received any lessons. Before this course, they had not been taught any instructional models, so the subject matter was completely new for them. Furthermore, all students were accustomed to working with multimedia computers in their studies, and the experiment took place in the classroom in which they normally had their computer-based classes. The students were randomly divided over the experimental groups, with 30 students in the VN-group (visual text, no cues in diagram), 26 in the VC-group (visual text, cues in diagram), 27 in the AN-group (audio, no cues in diagram), and 28 in the AC-group (audio, cues in diagram).

Materials

Multimedia instructions

For this study we developed multimedia instructions on the four-component instructional design (4C/ID) model of Van Merriënboer (1997). This model describes a design strategy for the training of complex cognitive skills. The instructions focused on how to develop a blueprint for a training programme based on the skills hierarchy of a complex skill. The material was constructed as a website with a linear structure that offered two worked-out examples followed by a general explanation of the design strategy.

The instructions started with two pages containing a short textual introduction to the 4C/ID model. Afterwards, a series of six diagrams followed, representing skill hierarchies and sequences of learning tasks. Together, these six diagrams formed the first worked-out example showing the different stages in developing a blueprint for the training of the complex skill *doing experimental research*. The second worked-out example consisted of three diagrams showing the same process of developing a blueprint for the training of the complex skill *designing a house*, and finally the strategy of the 4C/ID model was summarised in two general diagrams. All 11 diagrams were accompanied by a textual explanation on how the model was applied in the specific situation.

Four versions of the instructions were created that differed in the way the text accompanying the 11 diagrams was presented, and in the use of visual cues in the diagrams. In the two audio versions, students could listen to the text that accompanied the diagrams through a headphone, while in the two visual versions exactly the same text was depicted in a textbox above the diagrams. All explanatory texts (both in the audio and in the visual versions) were split into smaller fragments of one to four sentences long, and these text fragments were presented one by one. In the audio versions it was possible to replay each text fragment by clicking on a small *play* button. Figure 1 shows a screen example of the visual version of the instructions, with a diagram and a small fragment of the explanatory text in a fixed position at the top, whereas Figure 2 shows the same screen in the audio version, with a button to replay the same text fragment after it has finished playing.

Each fragment of an explanatory text referred to a specific part of a diagram. In the two cued versions of the instructions, these parts of the diagrams were coloured bright red to reduce visual search, whereas in the two non-cued versions no colour coding was used. In all four versions of the instructions students could read or listen to a text fragment as many times as they wanted, look in the diagram where the text referred to, and then either continue with the next text fragment by clicking on a forward arrow or return to the previous text fragment (if there was one) by clicking on a backward arrow. If a student clicked on one of the arrows, the diagram stayed the same; only the accompanying text fragments and the visual cue in the diagram (if any) changed.

Mental effort measure

The self-report measure of mental effort used in this study was a 9-point rating scale ranging from *very, very low mental effort* to *very, very high mental effort*, and was developed as a non-intrusive measure of cognitive load by Paas (1992). The average score on the 11 mental effort rating scales used in the instructions (one for each diagram) was taken as a measure of mental effort during instructions (Cronbach's alpha = .92).

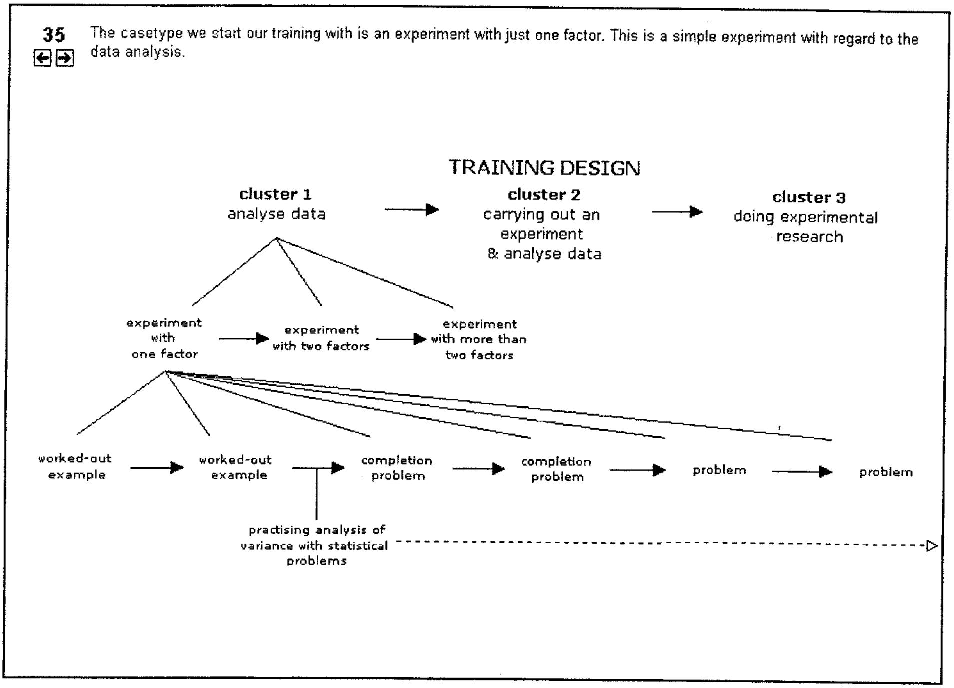

Figure 1. Screen example of the VN-version (visual text, no cues in picture), showing a diagram of a learning sequence accompanied by a small fragment of the explanatory text at the top. By clicking on one of the arrows next to the page number students could get to the next or previous text fragment

Retention test

The retention test originally consisted of two paper-and-pencil tests, one of 30 and one of 20 multiple-choice items. The 30-item test contained only verbal statements, while the 20-item test combined the verbal statements with small parts of diagrams. All items were statements about the 4C/ID model like 'A macro-sequence in the 4C/ID model is a series of subskills in a cluster', or 'According to the 4C/ID model, the same subskills can be trained in more than one learning task', and the students could choose between *correct*, *incorrect* or *I don't know*. Each right answer yielded 1 point. Together, the sum of the scores on all 50 items formed one total retention score (Cronbach's alpha = .67).

Transfer test

The transfer test was also a paper-and-pencil test and consisted of a short description of the skills that an expert researcher applies when searching for literature, in combination with the assignment to design a blueprint for the training of this complex skill on a blank answering form. To score the results of the transfer test, a scoring form was developed consisting of 40 *yes/no*-questions that checked to what extent and how accurately the strategy prescribed by the 4C/ID model had been applied in the transfer task. Every *yes* scored one point, and the sum score ranged from zero (no steps from the model taken) to 40 (all steps taken accurately). After the experiment, three independent raters scored the transfer tests using the form. The tests of 26 students were scored by all three raters, showing an inter-rater agreement of .88 (calculated as a single measure intraclass correlation, see McGraw & Wong, 1996).

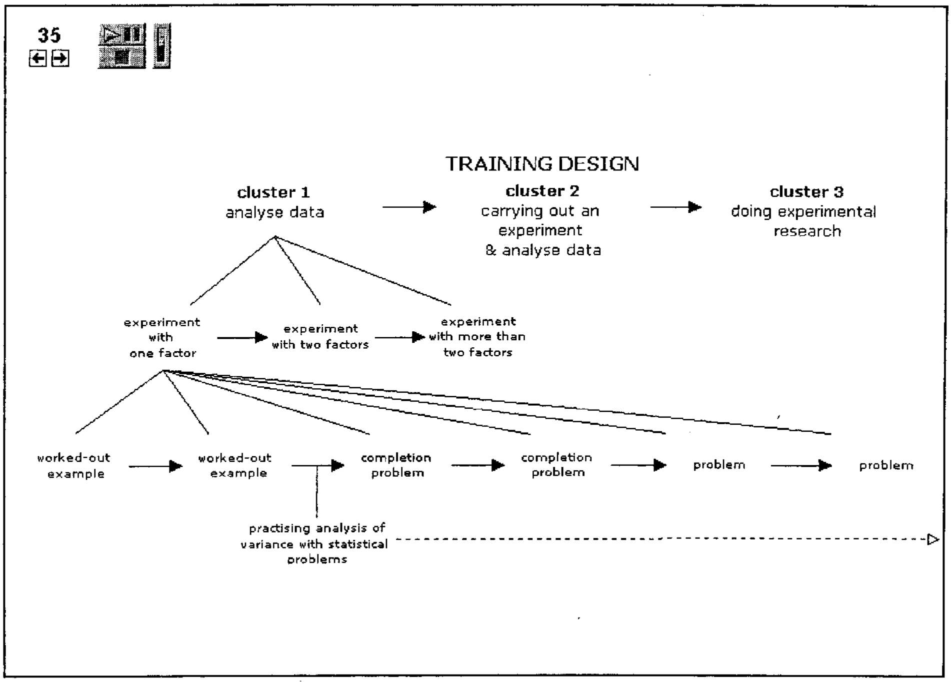

Figure 2. Screen example of the AN-version (audio, no cues in picture). When a student opened a page, the audio fragment started playing automatically. After it had finished, the student could replay it by clicking on the little play-button in the upper left corner. By clicking on one of the arrows next to the page number students could get to the next or previous text fragment

Procedure

The experiment was carried out in three sessions, and in each session between 35 and 40 students were tested simultaneously. These sessions took place in a classroom that had 40 multimedia computers connected to the Internet through the university network, with 10 computers for each experimental condition. The computers that delivered bimodal instructions had headphones attached to them. The headphones used in the experiment were 'open', so that surround noise was still audible. When the students entered the room, they were randomly assigned to one of the computers. Each computer showed a browser-window (without any of the menu options visible) set on a web page with some general information on how to navigate in the instructional material and how to complete the mental effort scales that were administered during the instructions. In the two audio conditions, students were reminded that they had to wear the headphones during the instructions. Furthermore, it was announced that the students would be tested after the instructions.

All students started at the same time and were given a maximum of 70 minutes to study the instructional material. If they finished earlier, they could do something for themselves in silence, but they were not allowed to leave the classroom or talk to other students. The server on which the instructional website ran kept record of the time spent on the learning task and of the mental effort scores of each participant. After each diagram in the instructions, a separate page followed with a subjective rating scale on which the students could rate the mental effort they had spent. When a student clicked on one of the options of the rating scale, the program automatically continued with the next diagram.

After the instruction phase the three paper-and-pencil tests were administered. Maximum time for each retention test was 10 minutes, and in the transfer test the students got a maximum of 30 minutes to design a training programme. After each test the students rated their mental effort on a 9-point scale similar to the ones used in the instructions. At the end, the students were asked to complete a questionnaire to evaluate how they had experienced the experiment and whether there had been any problems with either the computer or the instructional material. Each session took about 2½ hours.

Results

The variables under analysis were training time, mental effort spent on instruction and on the tests, retention score and transfer score. All scores were analysed with two-factor analyses of variance (ANOVAs), with modality (visual vs. spoken text) and cueing (no cues vs. cues in the diagram) as the between-subjects factors. For all statistical tests, a significance level of. 05 was applied. Table 1 shows the average scores on the dependent measures for all four conditions.

Table 1. Means and standard deviations of dependent measures for all conditions

	Condition VN (n = 30)		Condition VC (n = 26)		Condition AN (n = 27)		Condition AC (n = 28)	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Training Time (Minutes)	47.8	7.5	48.1	7.1	56.6	7.0	58.0	7.0
Mental Effort during Instructions (1–9)	4.1	1.1	4.2	0.8	3.7	0.8	3.9	1.1
Mental Effort on Retention Tests (1–9)	6.7	0.9	6.9	1.0	6.2	1.1	6.0	1.2
Mental Effort on Transfer Test (1–9)	6.4	1.4	6.9	1.4	6.3	1.4	6.4	1.5
Retention Score (0–50)	32.2	4.8	33.5	5.7	28.1	5.2	30.6	4.6
Transfer Score (0–40)	21.6	6.2	22.2	6.7	17.9	5.6	20.0	6.1

Training time was not equal for all conditions, with participants in the visual conditions (M = 47.9 minutes, SD = 7.2) needing significantly less time than participants in the audio conditions (M = 57.3 minutes, SD = 7.0), $F(1,107) = 47.27$, $MSE = 51.25$, $p < .001$. However, the results of the evaluation questionnaire showed that the slower downloading of the audio files over the Internet accounted for at least part of the difference.

The average mental effort score during instructions was 4.0 (SD = 1.0), which represents a rather low mental effort. The students in the visual conditions (M = 4.2, SD = 1.0) spent a little more effort on the instructions than their colleagues in the audio conditions (M = 3.8, SD = 1.0). However, this difference did not reach statistical significance, $F(1, 107) = 3.16$, $MSE = 0.93$, $p = .08$. The mental effort score for the retention test did show a significant effect for the modality of instructions, $F(1, 107) = 11.84$, $MSE = 1.12$, $p < .01$, because students in the visual conditions ($M = 6.8$, $SD = 1.0$) reported more effort than their colleagues in the audio conditions ($M = 6.1$, $SD = 1.1$). No significant differences were found on the mental effort scores for the transfer test.

A significant effect for the modality of text was found in the retention test, with the visual conditions ($M = 32.8$, $SD = 5.2$) scoring significantly higher than the audio conditions ($M = 29.4$, $SD = 5.0$), $F(1, 107) = 13.13$, $MSE = 25.72$, $p < .01$. The effect of adding cues to the diagram also reached statistical significance, $F(1, 107) = 4.02$, $p < .05$, with a higher score for the cued conditions ($M = 32.0$, $SD = 5.3$) than for the no-cues conditions ($M = 30.3$, $SD = 5.4$).

The scores on the transfer task showed a significant effect for the modality of the text, $F(1,107) = 6.49$, $MSE = 37.62$, $p < .05$, in the same direction as in the retention test (visual text: $M = 21.9$, $SD = 6.4$; audio: $M = 19.0$, $SD = 5.9$) but no effect for cueing.

Discussion

It is clear from the results that the modality and the cueing effects demonstrated in earlier experiments on multimedia instructions have not been replicated in this study. First, the presumed positive effect of adding visual cues to the diagrams is only noticeable in the results of the retention test but not in the transfer test or in any of the mental effort measures. Second, regarding the hypothesised superiority of spoken text over visual text, the results on the tests are even contrary to expectations. Students in the visual conditions perform better than students in the audio conditions on both retention and transfer tests. In terms of the efficiency of the different presentation formats, the results are somewhat mixed. The mental effort that students spend in the audio conditions is marginally less than the effort that is spent in the visual conditions, which seems to be in line with what Kalyuga *et al.* (1999, 2000) and Tindall-Ford *et al.* (1997) have found. Moreover, in the retention test the students in the visual conditions report higher mental effort scores. So the fact that they have obtained higher retention scores can at least partly be explained as a result of investing more mental effort. However, on the transfer test no differences in mental effort appear that can explain the difference in transfer score. Finally, students in the visual conditions have spent significantly less time on the instructions, which only strengthens the conclusion that they have really outperformed their colleagues in the audio conditions.

Why do our results differ so significantly from earlier research on multimedia learning and cognitive load, especially regarding the modality effect? First of all, this study was designed to test the generalisability of the modality effect in a more ecologically valid classroom setting. That may have introduced confounding factors that were excluded in the earlier experiments in controlled laboratory settings. One could easily think of factors like the simultaneous testing of 30 or more students or the use of a flexible but somewhat unstable delivery medium as the Internet. Moreover, in the audio conditions, downloading the fragments took some time, which might have resulted in loss of motivation in the students. Finally, students spent more than an hour studying the instructional material, which contrasts sharply with the few minutes instructions used in earlier research on the modality effect. Differences in extraneous load that have an influence in short learning tasks may lose their influence as more time-related factors become dominant in the learning process, such as concentration and span of attention. Listening might be even more tiresome or boring than reading, resulting in less motivation. However, the mental effort measures during instruction do not indicate large differences between the conditions, and also the results from the evaluation questionnaires give no indications of differences in motivation or concentration during the instructions. So it does not explain why we find a reverse modality effect.

Another explanation might be that the multimedia instructions used in the present study differ in two ways from the instructions used in earlier studies, both in subject matter and in pacing. First of all, it can be argued that instructional design strategies are more procedural and less descriptive in nature than for example the scientific explanations used by Mayer and Moreno (1998; Moreno & Mayer, 1999). Visual text might be more suitable for presenting procedural information than spoken text, as the learner has more time to reflect on the information. On the other hand, students in the audio conditions had the opportunity to listen to a piece of text as many times as they wished, giving them ample opportunity to elaborate on the information.

The pacing of the instructions might be a more plausible factor explaining why bimodal instructions were not superior to visual-only instructions. This could explain why students in the audio conditions achieved lower test scores. In the studies by Mayer and Moreno (1998; Moreno & Mayer, 1999) and Kalyuga *et al.* (1999, 2000) the multimedia instructions were presented as system-paced animations. In the present study, however, the learners could scroll through the explanatory texts at their own pace. Possibly bimodal instructions are only advantageous when animations are system-paced, whereas visual-only instructions are more effective when the learner can set the pace. The advantage of bimodal instructions is that the picture and the text can be perceived simultaneously, resulting in a lower extraneous load than in visual-only instructions where the learner has to skip between text and picture in a limited time. In learner-paced instructions, however, this advantage disappears because the learner with the visual-only instructions has more time to relate the text to the picture. Moreover, with visual texts it is much easier to jump back and forth through the text than with spoken texts that are linear by nature and are much less easy to skim through. So learner pacing could make visual-only instructions more effective than bimodal instructions and reverse the modality effect. In future research, this hypothesis should be investigated by comparing system-paced with learner-paced bimodal instructions.

Taken together, the results of this study show that the design principles that adding visual cues to pictures and replacing visual text with spoken text will increase the effectiveness of the instructions in multimedia instructions are simply not generally applicable. Although we did find a small positive effect of cueing in our experiment, we could not replicate the modality effect found in earlier studies. Replacing visual text with spoken text even had a negative effect on learning, contrary to what both cognitive load theory and Mayer's theory of multimedia learning would predict. It seems that a bimodal presentation is only advantageous when the system sets the pace of the instructions, whereas visual-only instructions are the preferred format if the learner is in control. Further research into the conditions under which the modality and cueing effects occur might produce more specific design principles for multimedia instructions that can successfully be applied in real-life educational settings.

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