Multimedia instructions and Cognitive Load Theory: split-attention and modality effects[1]

Paper presented at the AECT 2000 in Long Beach, California

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Despite the huge production of all sorts of multimedia instructions, educational research has yielded surprisingly few general design principles for instructions in which verbal and visual information are combined. Instructional designers seem to base their design choices more on intuitive ideas than on sound research results. There are however some interesting theories that give guidelines for instructional designers. Mayer (1997) describes in his Generative Theory of Multimedia Learning how the learner builds mental representations of multimedia material. One important step in this process is the integration of both visual and verbal information. Multimedia instruction in its most elementary form consists of a picture with an explanatory text. Because picture and text cannot be perceived simultaneously, the learner is forced to switch back and forth between the two and integrate them mentally. According to Cognitive Load Theory (Sweller, 1988; Sweller, van Merriënboer & Paas, 1998) this integration process is cognitively demanding and at the expense of mental resources that could otherwise be allocated to the learning process. Sweller et al. call the unnecessary cognitive load caused by the presentation format of instructions *extraneous* load. A design guideline that follows from Cognitive Load Theory is to keep the extraneous load of instructions as low as possible, so that the available mental resources can be used for the actual learning process. In their empirical research, Sweller and his co-workers have demonstrated a number of ways in which the extraneous load of instructions can be influenced. In our study we compared two ways of lowering the extraneous load of multimedia instructions, preventing split-attention and presenting text as audio, in order to find out which one is more effective.

Sweller and his colleagues demonstrated in a series of experiments that physical integration of verbal and visual information prevented the learner from splitting his or her attention between text and picture, which lead to better learning results (Chandler & Sweller, 1991; Chandler & Sweller, 1992; Sweller, Chandler, Tierney & Cooper, 1990; Tarmizi & Sweller, 1988). By placing a textbox next to the part of the picture the text was referring to, the time needed to keep the information active in working memory was shortened resulting in a lower extraneous load. Sweller et al. (1998) call this phenomenon the *split-attention effect*. Instead of placing text inside a picture, Kalyuga, Chandler and Sweller (1999) used color-coding to link the text with corresponding parts of the picture. This way they prevented unnecessary visual search and also lowered cognitive load. Kalyuga et al. did not only try to measure the resulting learning benefits but also the mental effort learners had spent on studying the instructions. For this purpose they used a subjective rating scale developed by

[1] The experiment reported in this paper is part of a research project that is co-funded by SPC Group, a multimedia development company in Den Bosch, The Netherlands.

Paas and others (Paas, 1992; Paas & van Merriënboer, 1993; Paas & van Merriënboer, 1994; Paas, van Merriënboer & Adam, 1994).

The studies of Mayer and Moreno (1998), Mousavi, Low and Sweller (1995) and Tindall-Ford, Chandler and Sweller (1997) showed an alternative way of decreasing extraneous load. In their experiments, all texts were presented as audio, resulting in improved learning results. The authors explained their 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. So presenting information in two sensory modalities (visual and auditory) increases the available working memory resources and, comparatively speaking, decreases the cognitive load caused by the instructional format. This is called the *modality effect*. Jeung, Chandler and Sweller (1997) showed that this effect does not occur when the visual complexity of a picture is high. Only after adding visual cues to the picture they did find the modality effect. This finding raises the question if the explanation of the modality effect in terms of increased memory resources is a feasible one, or that the modality effect can also be explained in terms of preventing split-attention. After all, with the text presented as audio the learner can listen to a narration and at the same time look at a picture, which is impossible with written text. But if the complexity of a picture is high, the learner has to search the picture at the same time as he or she is listening to the text. That means that the text and corresponding parts of the picture are not perceived simultaneously causing a split-attention effect.

Almost all multimedia instructions used in the above-mentioned studies discussed subjects from technical domains like for example geometry (Mousavi, Low & Sweller, 1995; Tarmizi & Sweller, 1988) or computer programming (Chandler & Sweller, 1992; Sweller et al., 1990). The instructions consisted of worked examples or contained pictures of a model or machine in combination with a textual explanation of its functioning. In most cases, students had to study the learning material for only a few minutes, and were tested immediately afterwards.

In our study we wanted to investigate the question which design strategy is most effective in decreasing the extraneous load of multimedia instructions: preventing split-attention or presenting text as audio. For that goal we developed multimedia instructions in which we varied both the modality of the text and the use of visual cues. We compared four different conditions:

condition VN - visual text, no cues in the diagram;
condition VC - visual text, cues in the diagram;
condition AN - audio text, no cues in the diagram;
condition AC - audio text, cues in the diagram.

The two hypotheses that follow from Cognitive Load Theory are that presenting the texts accompanying the diagrams as audio will decrease the extraneous load (modality effect), and that adding visual cues to the diagrams will prevent visual search and also decrease extraneous cognitive load (split-attention effect). This implies that condition AC will lead to the lowest extraneous load, and that condition VN will lead to the highest extraneous load. The extraneous load caused by condition AN and VC will lie somewhere in between, and the difference between the two conditions will make clear which separate strategy is more effective, presenting the text as audio or adding visual cues. In order to measure the effectiveness of the instructions, we not only looked at the learning results but also at the mental effort the learners spent on the instructions. Paas and Van Merriënboer (1994) showed that mental effort is just one dimension of cognitive load that is not only influenced by task-characteristics but also by subject characteristics like prior knowledge and subject/task interactions like motivation. Because we were only interested in the influence of task-characteristics, we tried to exclude any subject characteristics by randomization of our subjects over conditions.

Our experiment differs from earlier research on the cognitive load of multimedia instructions in a number of ways. First of all, we looked at both the modality effect and the split-attention effect simultaneously to find out if there is a difference in effectiveness. Moreover, the instructions used in our experiment were much more extensive than in the previous studies, so the time spent on the instructions was much longer. Finally, the subject of the instructions was instructional design, a subject outside the technical domain.

Method

Participants

151 second-year students from the Department of Education of the University of Gent in Belgium participated in the experiment. The instructions presented in the experiment were part of a course on instructional design. At the time of the experiment, the students had not received any instruction on instructional design models yet.

Materials

The participants studied a website 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 and consisted of two worked-out examples followed by a general explanation of the design strategy. The first worked example demonstrated how to design a training for the complex skill 'doing experimental research', the second worked example did the same for 'designing a house'. The material consisted of eleven diagrams (skills hierarchies and sequences of learning tasks) with explanatory texts that were cut up into pieces of a few sentences long that could be scrolled through. (see figure 1) These diagrams After each new diagram, students had to rate the mental effort invested in understanding the instructions on a nine-point scale, ranging from *very, very low mental effort* to *very, very high mental effort*. This scale is identical to the one used by Paas (1992). The average of the eleven mental effort scores formed the mental effort score during instruction

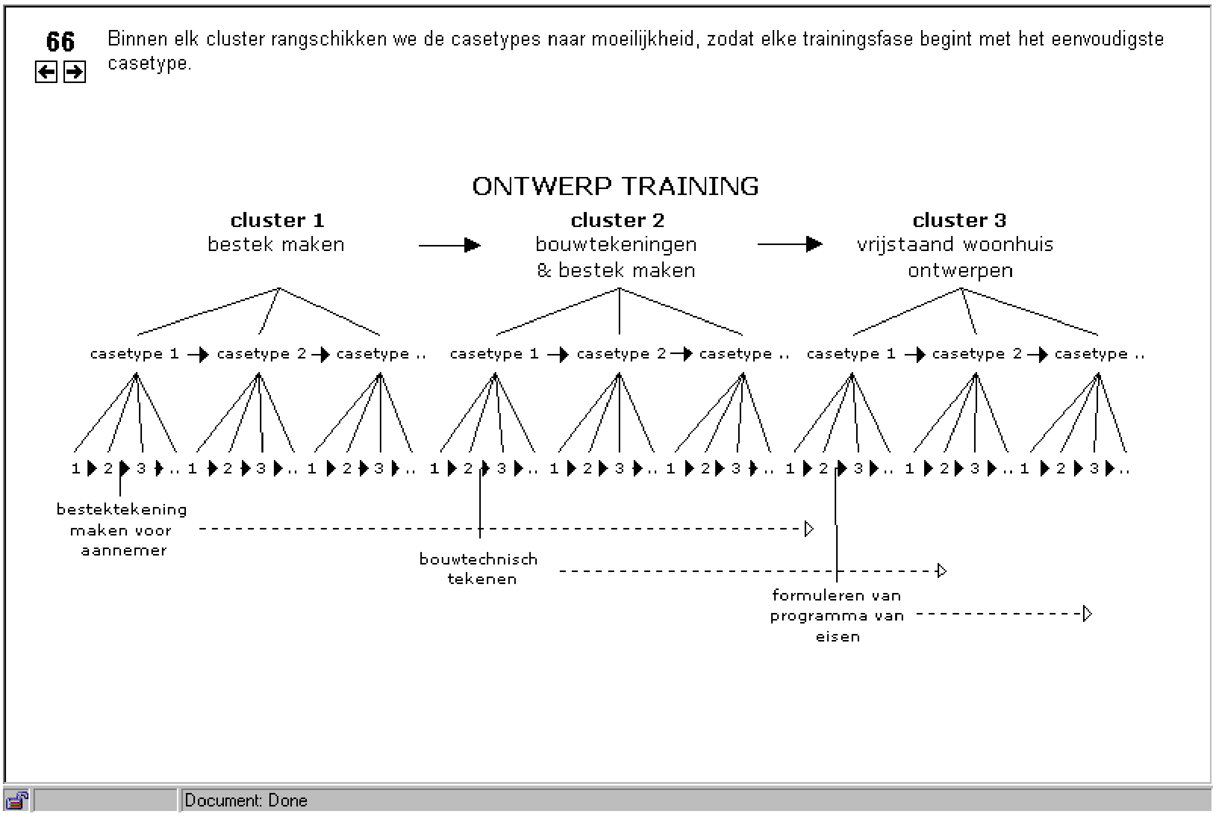

Figure 1. Example of the multimedia instructions: screen in condition VN

The four conditions differed in the way the texts accompanying the diagrams were presented and in the use of visual cues. In the audio conditions, the students listened to the texts through a headphone and were able to replay the audio by clicking a play-button, while in the visual conditions the texts were depicted above the diagrams. The visual cueing was done by coloring red those parts of the diagram the text referred to.

The reproduction test originally existed of two multiple-choice tests of 20 and 30 items. All items were statements about the 4C/ID-model like "A macrosequence 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*. The 30-item test only contained verbal statements, while the 20-item test combined small parts of diagrams with verbal statements. A right answer yielded one point, a wrong answer minus one point and not knowing zero points.

The transfer test contained a short description of the skills an expert researcher applies when he or she is searching for literature followed by the question to design a blueprint for the training of this complex skill according to the 4C/ID-model. To be able to judge the results of the transfer test we developed a scoring form that consisted of forty yes/no-questions to check to what extent and how accurately the strategy prescribed by the model had been applied. Every yes scored one point, and the total transfer scores were converted to percentages, ranging from zero (no steps from the model taken) to 100 (all steps taken accurately).

Procedure

The experiment was carried out in four sessions. These sessions took place in a classroom with forty multimedia computers, ten for each experimental condition. When the students entered the room they were randomly assigned to one of the computers.

First, the students read some general instructions on how to navigate through the instructional material and how to fill in the mental effort scale. In the auditory conditions, students were also reminded that they had to use the headphones. Furthermore, all participants were told that after the instruction phase they would have to make two multiple-choice tests and design a training. When the students had finished reading, they had the opportunity to ask any questions about the procedure. Then, the students simultaneously logged in onto the website with the instructional material by typing in their student number. They had a maximum of one hour to study the instructional material. If they finished studying the material beforehand, they could surf on the Internet until time was over. The server on which the instructional website ran kept record of the time spent on the learning task and of the mental effort scores.

After the instruction phase the computers were shut off and the three paper-and-pencil tests were administered. In two sessions students first got the two multiple-choice tests followed by the transfer test, while in the other two sessions the order was reversed to prevent any sequencing effect. Maximum time for each multiple-choice test was ten minutes, and students got thirty minutes to design a training in the transfer test. After each test students also rated the mental effort spent on the test.

After item analysis we combined both multiple choice tests in one total reproduction score of 35 items (Cronbach's alpha = 0.73). Three independent raters rated the results on the transfer test with an interrater reliability of 0.95.

Results

Time on learning task (M = 3227 s; SD = 549 s) was left out of the analyses, because server problems had created differences that couldn’t be attributed to the experimental conditions.

Figure 2 shows the pattern in time for the eleven separate mental effort scores during instructions. This pattern was identical in all four conditions and followed mainly the increasing complexity of the diagrams used.

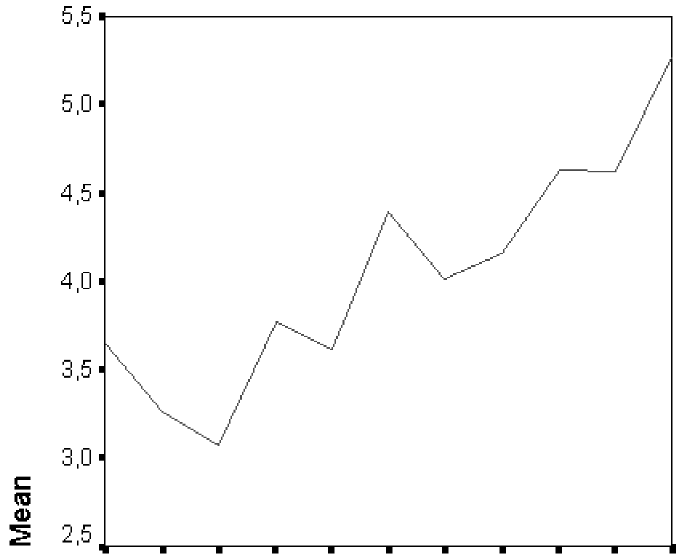

Figure 2. Mean scores for the eleven separate mental effort scales used in the instructions.

The variables under analysis were reproduction score, transfer score, and mental effort spent on both instruction and tests. For all statistical tests, a significance level of 0.05 was used. All scores were analyzed with two-way analyses of variance (ANOVAs). Table 1 shows the scores for the different conditions.

	condition VN (n = 40)		condition VC (n = 36)		condition AN (n = 36)		condition AC (n = 39)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
mental effort during instructions (1 - 9)	4.1	1.0	4.2	0.9	4.0	0.9	4.0	1.0
reproduction score (-35 – 35)	16.5	7.9	18.6	7.8	11.9	7.3	14.7	7.0
mental effort on reproduction test (1 - 9)	6.5	1.0	6.6	1.1	6.3	1.1	6.1	1.1
transfer score (0 – 100)	70	20	69	20	60	17	68	19
mental effort on transfer test (1 - 9)	6.6	1.5	7.0	1.2	6.3	1.4	6.5	1.4

Table 1. Scores on dependent variables for all four conditions.

The average score for mental effort during instructions was 4.1 (*SD* = 0.95), and the effect of condition was not statistically significant (F = 0.44, p > 0.10). For the reproduction score however, there was a significant effect for the modality of text (F = 11.8, p < .001), with the visual conditions scoring better than the audio conditions (*M* = 17.5, *SD* = 7.9 and *M* = 13.4, *SD* = 7.2, respectively). The effect of adding cues to the diagram also reached statistical significance (F = 3.8, p = .05), with a higher score for the cued conditions (*M* = 16.5, *SD* = 7.9 versus *M* = 14.3, *SD* = 7.2 for the non-cued conditions). The mental effort during the reproduction test also showed a significant effect for the modality of instructions ($F = 5.0$, $p < .05$). Students in the visual conditions ($M = 6.6$, $SD = 1.0$) had spent a little more effort than their colleagues in the audio conditions ($M = 6.2$, $SD = 1.1$).

The scores on the transfer task showed a different pattern, with a deviating score for the AN-condition. However, only a marginal significant effect for the modality of the text ($F = 3.2$, $p = .07$), in the same direction as in the reproduction test ($M = 70$, $SD = 20$ for the visual conditions, $M = 64$, $SD = 19$ for the audio conditions). There were no significant differences in the mental effort spent on the transfer task.

Discussion

It is clear from our results that the strategies from Cognitive Load Theory that would help to lower the extraneous load of multimedia instructions seem to have failed, because the mental effort spent on the instructions is almost equal for all conditions. That could mean that the differences in extraneous load between the conditions were very small, and that the measurements were too rough to notice it. However, the results also show that students report large differences in mental effort scores for different diagrams, which indicates a considerable sensitivity of the scale used. An alternative explanation for the lack of difference in reported mental effort is that students have compensated a lower extraneous load with a higher learning effort, resulting in an equal mental effort score. In that case, the scores on the tests demonstrate which presentation mode has led to the most efficient use of mental resources.

From the test results it seems that preventing visual search by adding visual cues to the diagrams has been effective. Students that have received the cues are scoring higher on the reproduction test than students that haven't. However, this advantage disappears in the transfer test, except for a small effect in the audio conditions. The second strategy that we applied, replacing text with audio, has not produced the increase in effectiveness as was expected. The test results do show a modality effect, only it is exactly opposite to what Cognitive Load Theory would have predicted. The students in the visual condition have scored better on the reproduction test than the students in the audio conditions. However, the higher reproduction scores are coupled with a higher mental effort spent on the test, which could partly explain the difference.

Taken together, our results do not give a straight answer to the question which strategy is best for lowering the extraneous load of multimedia instructions. Adding cues to a diagram or picture shows a little improvement in terms of learning effect, but not as strong as could be expected from earlier research. Replacing text with audio has even had a negative effect on learning in our multimedia instructions contrary to the expectations. These results do raise a new question: Why do our results differ from those achieved with earlier research on multimedia instructions and Cognitive Load Theory? There are a few possible answers.

First of all, the average mental effort during instructions in our study is not high, even below average. That could mean that students have not really been motivated to study the instructions. However, the effort scores on the tests are above average, and the learning results are reasonable given the difficulty and novelty of the subject.

Another explanation for the absence of strong effects may be the time spent on the instructions. In our experiment, students spend almost an hour on studying the instructional material. Differences in extraneous load that do have an influence in short tasks, may loose their influence as other more time-related factors are becoming dominant in learning processes, such as concentration and span of attention.

A final explanation is more in line with Cognitive Load Theory itself. It is possible that while the students were studying parts of the instructions became redundant because students did not need to see and read or hear things for a second time. In the visual conditions, it would be easier to skip through texts and only study what’s relevant than in the audio conditions. That would mean that in the audio conditions the mental resources were partly used for processing unnecessary information, leading to a higher extraneous load and undoing the benefits of the modality effect.

The explanations mentioned above are of course quite speculative and need to be investigated in detail. However, the results found in our experiment do show that the guidelines for the design of multimedia instructions as described by Cognitive Load Theory only apply under certain conditions, and are not generally applicable. That may be a disappointment to the designer who is looking for clear-cut rules that tell him or her what to do. On the other hand does Cognitive Load Theory present a theoretical framework that can be very useful in guiding the search for design guidelines. Especially the combination of mental effort scores and learning results gives a clear insight in the efficiency and effectiveness of instructions. And that is what every instructional designer should be interested in.

References

Baddeley,A. (1992). Working Memory. *Science, 255*, 556-559.

Chandler,P., & Sweller,J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 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.

Jeung,H., Chandler,P., & Sweller,J. (1997). The role of visual indicators in dual sensory mode instruction. *Educational Psychology, 17*(3), 329-343.

Kalyuga,S., Chandler,P., & Sweller,J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13*, 351-371.

Mayer,R.E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32*(1), 1-19.

Mayer,R.E., & Moreno,R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*(2), 312-320.

Mousavi,S.Y., Low,R., & Sweller,J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87*(2), 319-334.

Paas,F.G.W.C. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.

Paas,F.G.W.C., & van Merriënboer,J.J.G. (1993). The efficiency of instructional conditions: An approach to combine mental effort and performance measures. *Human Factors, 35*, 737-743.

Paas,F.G.W.C., & van Merriënboer,J.J.G. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6*, 351-371.

Paas,F.G.W.C., van Merriënboer,J.J.G., & Adam,J.J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills, 79*, 419-430.

Sweller,J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

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*(2), 176-192.

Sweller,J., van Merriënboer,J.J.G., & Paas,F.G.W.C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251-296.

Tarmizi,R.A., & Sweller,J. (1988). Guidance during mathematical problem solving. *Journal of Educational Psychology, 80*(4), 424-436.

Tindall-Ford,S., Chandler,P., & Sweller,J. (1997). When two sensory modes are better than one. *Journal of Experimental Psychology: Applied, 3*(4), 257-287.

van Merriënboer,J.J.G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training*. Englewood Cliffs, NJ: Educational Technology Publications.