

THE IMPACT OF EXTERNAL GRAPHICAL REPRESENTATIONS IN DIFFERENT KNOWLEDGE DOMAINS: IS THERE A DOMAIN EFFECT?

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Abstract

In this paper three studies question the generalizability of Mayer's Cognitive Theory of Multimedia Learning (CTML) to the knowledge domain of the social sciences. The first research builds on the assumption that this knowledge domain differs in the way instructional designers develop depictive external graphical representations and the way students understand these representations. The key variable in this process is being (un)acquainted with the iconic sign system that is used to develop the representations in this knowledge domain. The research results reveal that studying learning materials enriched with external graphical representations in the social sciences domain does not result in higher test performance and does not result in lower levels of cognitive load. The second research builds on these former results and questions under which condition the performance on retention and transfer tests can be increased. Therefore a new design principle *activation* is put forward. Results show that the performance on the retention and transfer tests is higher when the learner actively builds his/her personal external graphical representations. The active construction of personal external graphical representations positively influences the performance on retention and transfer tests. The results of the second study are the starting point of the third research that focuses on the differential impact of the types of personal external graphical representations learners add to textual learning materials.

Multimedia Learning in Social Sciences: Impact of the Knowledge Domain

The Cognitive Theory of Multimedia Learning (CTML), put forward by Mayer (2001a), presents a clear framework to direct instructional design of both printed and interactive multimedia materials. Despite the theoretical and practical appeal of the theory for instructional designers, daily teaching experience of the authors of the present paper, responsible for freshman courses in the knowledge domain of educational sciences, is not always in line with the CTML. It appears that students cope with external graphical representations such as schemas, tables and graphs added to learning materials. And, as will be discussed in the next sections, recent research is not always able to replicate the positive findings that have been reported in earlier CTML-studies in other knowledge domains. The authors suggest that the nature of the knowledge domain and the nature of the external graphical representations interact with the validity of the CTML-design principles. By testing the original CTML-design principles in another knowledge domain questions about extending and/or generalizing the cognitive theory of multimedia learning are raised.

Basic Assumptions and Design Guidelines of CTML

Cognitive processing of information is the concept from which Mayer (2001a, 2003) starts to formulate three central assumptions of the Cognitive Theory of Multimedia Learning (CTML): the dual channel assumption (Baddeley, 1992; Chandler & Sweller, 1991; Moore, Burton & Myers, 1996; Paivio, 1978; Paivio, 1991; Nelson, 1979; Broadbent, 1956; Shannon & Weaver, 1949; Mayer, 2001a; Mayer, 2003), the active processing assumption (Wittrock, 1989; Mayer, 2001a; Mayer, 2003) and the limited capacity assumption (Sweller, 1988; Sweller, 1989; Sweller, 1994; Mayer, 2001a; Mayer, 2003).

This leads to the following design principles (Mayer, 2001a; Mayer 2001b; Mayer, 2003): (a) the *multimedia principle*: learners benefit more from printed text enriched with pictures than from printed text alone, (b) the *temporal contiguity principle*: learners perform better when corresponding printed text and pictures are presented simultaneously instead of successively, (c) the *spatial contiguity principle*: learning is fostered when printed text and pictures are presented close to one another on a page or on screen, (d) the *coherence principle*: learning performance is higher when extraneous sounds, words, pictures are excluded, (e) the *modality principle*: learners learn more from animation enriched with audio (narration) than from animation enriched with printed text, (f) the *redundancy principle*: learners perform better when presented with animation and narration instead of animation and narration combined with printed text matching the narration, and (g) the *individual differences principle*: all design principles have a stronger impact with low prior knowledge learners and learners with higher spatial abilities (see Mayer, 2001a, 2001b and 2003 for an overview). The generic nature of these design principles for all knowledge domains and types of external graphical representations is stressed by Mayer (2001a), but is questioned in this paper.

External Graphical Representations

First generation research focused on generic principles to understand consistencies in the processing of verbal and visual information (Anglin, Towers, & Levie, 1996; Goldman, 2003). Second generation research focuses rather on the affordances of and acquaintance of the students with iconic sign system as reflected in external graphical representations and this in relation with the nature of knowledge domain.

Verbal and pictorial representations behold a clear difference subscribed by Mayer. Verbal representations such as text (descriptive), require more mental effort to be processed by the learner and pictorial representations (depictive) are considered as being more original modes of knowledge representation and are more intuitive, closer to visual experience (Mayer; 2001a, p. 68).

Being acquainted with descriptive and depictive representations can influence the processing of the representations by the learners. As to the depictive representations, the question is raised whether the learners have sufficient and adequate prior knowledge that directs their understanding of these representations. Prior knowledge related to the mastery of the iconic sign system that is at the base of the external graphical representations is needed. When learners are confronted with new or unknown iconic sign systems, this is expected to result in learner difficulties (e.g. weaker processing and/or more processing time needed). It points at a mismatch between the iconic sign system of a learner and the one used in the external graphical representations (De Westelinck, Valcke, De Craene and Krischner, in press). The same idea has been put forward by other authors in the literature, but has yet not been related to CTML (Stenning, 1999; Dobson, 1995; Goodman, 1976; Lewalter, 2003; Goldman, 2003).

Considering the issue of familiarity with the iconic sign system, the *activation principle* is introduced in this paper. According to this principle, learners are invited to develop their own external graphical representation; thereby building on an iconic sign system they are familiar with. By developing a personal external graphical representation, learners are forced to process the new knowledge elements and to construct a visual mental model, next to the model based on text. This process also reinforces the familiarity with the personal iconic sign system. Several authors promote this *activation principle* (Marzono, Pickering & Pollock, 2001; Wileman, 1993).

The first study: CTML in the social sciences

Hypotheses

The central hypothesis put forward in this first research is that learners in the social sciences knowledge domain will experience difficulties with external graphical representations; thus resulting in non-confirmation of the original CTML hypotheses. The unfamiliarity with the iconic sign system used to develop the external graphical representations can have an influence on the selection, processing and organisation processes of mental models. Students are e.g., expected to experience cognitive load due to being not familiar with the iconic sign system. Confirmation of this overall hypothesis implies that the CTML-design guidelines are to be extended by a supplementary design principle that considers the mastery of the iconic sign system by the learner and the nature of the knowledge domain. The theoretical position about the nature of external graphical representations is applicable to both static (e.g., graphs) and dynamic (e.g., animations) external depictive representations.

In the first study, hypotheses related to five CTML-design principles were tested: the multimedia, spatial contiguity, coherence, modality and redundancy principle. In addition a sub-hypothesis was tested, in relation to each of the former hypotheses, whether application of the principles did lead to higher or lower levels of cognitive load as reported by the subjects.

Research Method

Participants

In total 190 freshmen, the entire first year student population studying educational sciences, participated in this study (academic year 2002-2003). Participation was a formal part of the course "Instructional Sciences". Informed consent was obtained from all students prior to experimentation.

Procedure

Three to six experiments were set up during two consecutive weeks in relation to each of the five CTML design principles. Students were randomly assigned to the experimental conditions. Each experimental package consisted of (a) a prior knowledge test consisting of a retention and transfer test, (b) a specific elaboration of the learning materials to be studied, and (c) a post-test to test the mastery of the complex knowledge elaborated in the learning materials (retention and transfer questions). Twice, the students were asked to estimate their perceived *mental effort*. Literature and research confirm the validity and reliability of this approach to determine cognitive load (Van Gerven et al., 2002; Paas et al. 1994; Paas, 1992; Gopher & Braune, 1984). No time limit was set to study the materials and/or to fill out the tests. The answers to the retention and transfer questions were scored by

three independent researchers based on a scoring checklist. Scores for the tests were standardized.

Materials

The content of the learning materials was both complex and new to the students: an introduction to the learning styles literature (the learning content). Nine themes were outlined to be presented to the students. Mayer’s recommendations were taken into account when developing the external graphical representations. *Figure 1* depicts a sample page of printed learning materials with integrated external graphical representations about Kolb’s learning style approach. It is clear from the example that the external graphical representations do not build on a formal and/or existing iconic sign system. Moreover, the approach is similar to the typical external graphical representations found in most psychology and educational sciences textbooks.

Type 1 Accomodator

A hands-on learner. This learner learns/works especially through intuition. Applying in a realistic environment is what he/she wants. There is a sensibility for feelings and interpersonal aspects.

Type 2 Diverger

Problems will be looked at from different points. Observing is chosen above active participating. Information is gathered and arranged. Imagination is the base for problem solving.

Type 3 Converger

Problem solving and finding practical solutions has the first choice. Technical problems are chosen above social or interpersonal subjects.

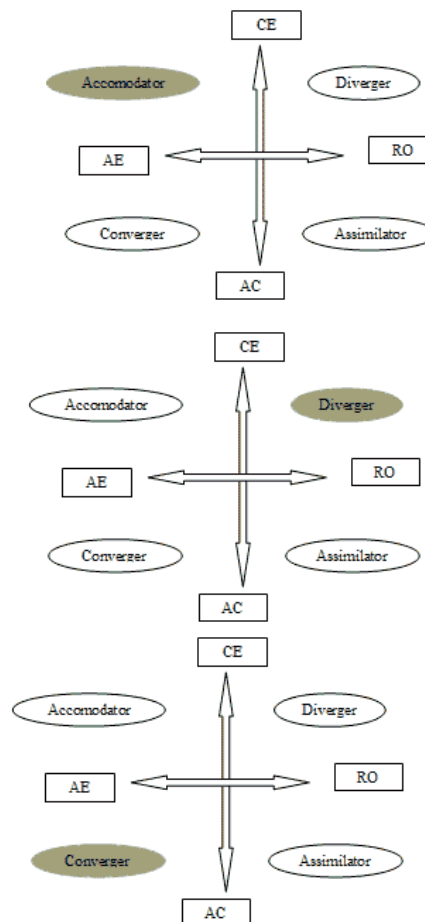


Figure 1. Example of learning materials related to the coherence principle building on the learning style model of Kolb.

Results and Discussion

Table 1 Summary of significant ANOVA results in study 1

	Multimedia principle	Spatial contiguity	Coherence principle	Modality principle	Redundancy principle
Week 1	$F(1, 69)$	$F(1, 67)$	<i>na</i> ^a	$F(1, 49)$	<i>na</i>
Exp 1: Transfer		8.74**			
Exp 1 Total test		8.74**			
Exp 2 Transfer	21.56*				
Exp 2 Total test	15.49*				
Week 2	$F(1, 48)$	<i>na</i>	$F(1, 85)$	<i>na</i>	$F(1, 49)$
Cognitive load			7.99*		

^aNot applicable. No experiments were set up to test this specific hypothesis during the session of this week. * $p < .01$ ** $p < .05$.

Multimedia principle

Students studying learning materials with no external graphical representations always attain higher mean post-test scores. Analysis of variance reveals (see Table 1) that these differences are significant for the second experiment with very large to large effect sizes $d = 1.12$ for the transfer test and $d = .95$ for the total post-test score. This suggests that the original CTML-hypothesis can not be confirmed for any of the six experiments related to this principle. This might confirm that learners have problems when studying from external graphical representations because of inadequate experience with or knowledge of the iconic sign system used. These results are consistent with Cox (1999), Lowe (2003) and Schnotz and Bannert (2003), and Dobson (1999).

Spatial contiguity

In 2 of the three experiments that helped to test this hypothesis, students obtain higher post-test scores when illustrations are not integrated into the text. These differences are significant in the first experiment, reflecting a medium effect size of $d = 0.72$. These results are not surprising in the light of the discussion of the first principle.

Coherence principle

In 2 of the three experiments to test the hypothesis about the impact of the coherence principle, students studying learning materials that consist of summaries with external graphical representations perform better on post-test questions. But none of these differences are significant. This questions the generic nature of the coherence design principle when external graphical representations are used that are depictive that are not based on a previously acquired iconic sign system.

Modality principle

In the three experiments, inconsistent results were observed in student performance. The condition where animations were enriched with audio did not consistently lead to higher performance as compared to conditions where the animations were enriched with text. Moreover, none of the differences in performance were significant. Also Tabbers, Martens and van Merriënboer (in press^b, 2001) could not replicate the CTML-findings in their studies. Of particular importance is the fact that in their study they also focused on less formal symbolic icon systems, used in the knowledge domain “research methodologies in social sciences”.

Redundancy principle

The post-test scores of students studying non-redundant learning materials; i.e., animation with narration and without additional text, were mostly higher. But the differences are not significant.

Cognitive load

The impact on cognitive load was tested in relation to each of the former five hypotheses. At a descriptive level, minor differences in cognitive load could be observed, but most differences are not significant. Only in the experiments related to the coherence principle, a significantly higher cognitive load was reported, reflecting a medium effect size of $d = 0.72$. But this significant effect is not in line with the CTML. Materials building on summaries with external graphical representations are – contrary to the CTML assumptions – invoking higher cognitive load than expanded versions with external graphical representations. This is in line with the research of Tabbers and others (in press^b). They also report inconsistent results as to the impact of external graphical representations on cognitive load.

The discussion in relation to the five experiments leads to rather consistent conclusions. In relation to each experiment, the analysis results do not confirm or reject the CTML-hypothesis. The practical implications of this finding are that instructional designers are expected to pay additional attention to the nature of the knowledge domain when developing external graphical representations. The results suggest that this is especially the case when students are not acquainted with the iconic sign system used to develop the representations.

The second research: the activation principle

Background and Hypotheses

The results of the first study revealed that the positive findings of Mayer could not be replicated in the social sciences. It was hypothesized that in the social science domain there is not an established conic symbol system shared by instructional designers, experts and novices to develop external graphical representations. From this hypothesis follows that students will not benefit from external graphical representations and that the CTML design principles would not hold. In a second study, this hypothesis was tested in an alternative way by adding a new design principle to Mayer's list: the *activation principle*. The central hypothesis for this second study is stated as follows: learners that are actively engaged in designing and developing their personal external graphical representations will perform better on post tests than learners studying learning materials with external graphical representations developed by others.

The *activation principle* can be readily linked to the CTML when focusing on the active processing assumption that founds this theory (2003). The selection, organisation and integration processes that foster the development of mental models presuppose that the learners are active. Developing personal external graphical representations is in the context of the present study put forward as a catalyst to promote these internal cognitive processes. Also other authors have suggested ways to foster the active processing (Burton, Moore, Magliaro, 1996; Seels, Berry, Fullerton, Horn, 1996; Driscoll, 2004; Van Hout-Wolters, Simons, and Volet, 2000). The *activation principle* can also be linked to the approach proposed by Novak (1998) and the theoretical base he puts forward to ground the use of concept maps. But it might also be hypothesized that asking learners to develop external graphical representations might invoke cognitive load (Sweller, 1988). Next to processing new

complex knowledge, students are asked to develop external representations. This extra process might hinder the construction of schemas in working memory and confront learners even faster with the limited capacity of their working memory; thus invoking a higher level of intrinsic cognitive load (Sweller, van Merriënboer & Paas, 1998). In the literature, there is plenty of reference to the relationship between cognitive load and prior knowledge (Kirschner, 2002). Several authors have made suggestions to cope with cognitive load and to reduce extraneous cognitive load. They put forward a variety of instructional design ideas and there is empirical evidence to support the positive impact of such measures (Paas, 1993; Stark et al. 2002; Sweller, 1999; Sweller et al (1998); van Merriënboer et al, 2002):

- Worked examples: learners work with exemplary partially solved problems.
- Goal-free problems: this helps learners to redirect their attention from a means-end strategy to a strategy in which they are invited to work forward from the given information.
- Hierarchical approach: this implies that based on a task analysis, learners tackle first the sub-components of the knowledge base before working on the more complex knowledge elements.
- Emphasis-manipulation approach: In the context of a problem, students are invited to tackle a specific sub-part of the problem.
- Completion strategy: students complete incomplete solutions. The next time they are expected to work on a larger incomplete problem.
- Expert-like problem analysis: students follow a specific set of questions that replicate the type of approach adopted by an expert.

In the present study, we take into account the potential negative impact on cognitive load and add an experimental condition in which student are presented with pre-worked external graphical representations. If the traditional CTML principles hold, the presentation of pre-worked representations is expected to require lower levels of mental effort from the learners. If the alternative hypothesis holds – the assumption that representations has to build on familiar iconic symbol systems – presenting learners with these pre-worked representations will still require more mental effort; thus reflecting more cognitive load.

Research Method

Participants

The entire population of freshmen, studying educational sciences ($N=217$) participated in this study (2003-2004). Participation was a formal part of the course “Instructional Sciences”. Informed consent was obtained prior to experimentation.

Procedure

Students were randomly assigned to one of the four experimental conditions: (1) studying printed learning materials with no external graphical representations, (2) learning materials with ready-made external graphical representations, (3) learning materials to which the students were invited to add their personal external graphical representations, and (4) learning materials with pre-worked external graphical representations.

In each condition, the students studied the learning materials that focussed at content level on complex and new knowledge about theories and models of *Instructional Design (ID)*. Three ID-sub themes were presented to the students in one single two hour session.

The three sub themes were presented in three subsequent experimental packages consisting of (a) a prior knowledge test consisting of a retention and transfer test, (b) a specific presentation of the learning materials to be studied, and (c) a post-test to

test the mastery of the complex knowledge elaborated in the learning materials (retention and transfer questions). Comparable to the first study, the students were asked twice to estimate their perceived *mental effort*. Again no time limit was set to study the materials and/or to fill out the tests. The answers to the retention and transfer questions were scored by three independent researchers based on a scoring checklist.

Results and Discussion

Table 2 presents a summary of the descriptive results. Analysis of variances, with the pretest results as the co-variable were carried out to compare post test results and measures of cognitive load. In case of statistically significant differences, Cohen's d was calculated to determine the effect size (Talheimer & Cook, 2002).

Table 3 gives an overview of the significant F-values when comparing the performance and cognitive load measures in the different conditions. The third experiment did not result in significant differences. This might be due to fatigue, given the duration of the study. But the results in relation to the first two experiments are clear. Students who are actively engaged in developing personal external graphical representations score higher on the retention and transfer tests (effect size $d = .66$ for the first experiment and $d = 0.54$ for the second experiment). These results suggest that the activation principle leads to better performance, but the results also confirm the CTML *multimedia principle*.

Significant differences are found in experiment two when comparing the group receiving learning materials with external graphical representations and the group developing personal external graphical representations, in favour of the latter (medium effect size $d = 0.63$). These results suggest that the *activation principle* is confirmed in this knowledge domain and when no formal iconic symbol system is available. The result in the other experiments show a comparable trend, but the differences are not significant.

Completing pre-worked external graphical representations versus developing personal external graphical representations results in significant differences with a large effect size ($d = .86$) in the second experiment. Students who develop personal representations show superior performance. The same trend is seen in the other experiments, but it is yet not significant.

These results are in line with the outcomes of other studies where activation was built in the learning materials. But the way *activation* is introduced is sometimes different. Lowe (2003), e.g., reports the positive impact of adding cues to focus the learners' attention to particular aspect of the representation, especially for learners with limited prior knowledge. A more direct activation was studied by Stern, Aprea and Webner (2003) who also asked their students to construct external graphical representations. concluded that active construction of graphs by students improves significantly knowledge transfer. Their results also underscore that the *passive study* of available graphs leads to lower test performance.

The results in relation to cognitive load reveal significant differences. Consistently, students that have to develop their personal external representations report significantly lower levels of mental load. But there is no significant difference between conditions that ask to develop completely new representations or to further develop pre-worked representations. These results obviously underscore the importance of the *activation principle*.

Table 2. Mean scores and standard deviation for performance measures and cognitive load in the second study

		Text without representations		Text with representations		Completing pre-worked representations		Developing representations	
		M^a	SD	M^b	SD	M^c	SD	M^d	SD
Experiment 1	Retention test	3.61	0.95	3.69	1.16	4.16	1.23	4.04	1.14
	Transfer test	7.91	3.41	9.22	3.45	8.44	3.36	9.96	3.48
	Total test score	11.52	3.60	12.91	3.70	12.59	4.01	14.00	3.87
Experiment 2	Retention test	1.57	0.89	1.65	0.83	1.71	0.87	1.95	0.84
	Transfer test	2.81	1.10	2.67	0.93	2.23	1.06	3.21	1.04
	Total test score	4.38	1.59	4.32	1.40	3.94	1.55	5.17	1.29
Experiment 3	Retention test	1.12	0.51	1.15	0.58	1.10	0.59	1.07	0.69
	Transfer test	1.91	1.92	2.18	1.79	1.89	1.69	1.56	1.57
	Total test score	3.03	1.93	3.33	2.10	2.99	1.98	2.62	1.99
		M^a	SD	M^b	SD	M^c	SD	M^d	SD
	Cognitive load 1	5.41	1.47	4.81	1.60	4.67	1.60	4.17	1.42
	Cognitive load 2	7.00	1.30	6.24	1.43	6.17	1.71	5.83	1.69
	Total cognitive load	12.43	2.34	11.07	2.69	10.35	2.99	9.94	2.59

^a $N = 54$. ^b $N = 55$. ^c $N = 54$. ^d $N = 54$.

Table 3. Overview of significant *F*-values ANOVA results

	Text without representations vs <i>Text with representations</i>	Text without representations vs <i>Completing pre-worked representations</i>	Text without representations vs <i>Developing representations</i>	Text with representations vs <i>Completing pre-worked representations</i>	Text with representations vs <i>Developing representations</i>	Completing pre-worked representations vs <i>Developing representations</i>
Experiment 1 Retention test	<i>F</i> (1, 108)	<i>F</i> (1, 107) 6.69**	<i>F</i> (1, 107) 4.45**	<i>F</i> (1, 108) 4.16**	<i>F</i> (1, 108)	<i>F</i> (1, 107)
Transfer test			9.61*			
Total test score			11.89*			
Experiment 2 Retention test			5.23**			
Transfer test		7.57*		5.33*	8.15*	23.43**
Total test score			7.97**		10.87**	19.90**
	<i>F</i> (1, 108)	<i>F</i> (1, 107)	<i>F</i> (1, 107)	<i>F</i> (1, 108)	<i>F</i> (1, 108)	<i>F</i> (1, 107)
Cognitive load 1		6.26*	19.80*		4.94*	
Cognitive load 2		7.93*	15.94*			
Total cognitive load		9.23**	26.73*		4.87**	

* $p < .01$.

** $p < .05$.

The third research: the nature of developing personal external graphical representations

Background and Hypotheses

Building on the results of the second study, a new study was set up that focused on the way students elaborate their personal external graphical representations. Students differ in the way they develop these external graphical representations. In this context we can refer to the concept of *visual thinking*, introduced by Wileman (1993). This is the ability to conceptualize and present thoughts, ideas and data as pictures and graphics, in order to replace much of the available verbal/textual representation. He distinguishes three overlapping strategies of thought: imaging, seeing and designing. The designing strategy is considered as a central element of activation. Wileman (1993) advocates that there are three types of symbols that can be used in visual thinking: pictures, verbal symbols and graphical symbols. The first category is not considered in the present study. The verbal symbols are defined as words. Graphical symbols consist of image-related graphics, concept-related graphics and arbitrary graphics. Image-related graphics are highly recognizable representations of an object or idea. Concept-related graphics remove as much detail as possible and make the knowledge object more abstract. Arbitrary graphics are abstract symbols conceived to show relationships between ideas. The *visual thinking* theory of Wileman was used to categorize the external graphical representations student had developed in their learning materials.

This third study centres on the hypothesis that the nature of the external graphical representation will have a differential impact. The more elaborated the representation, the higher the activation, the higher the cognitive processing in developing mental models. In the present study, an extra condition was added to the condition in which students were asked to develop their own personal external graphical representation next to the printed learning materials. In this new condition, students received training in developing external graphical representations. This extends the former hypothesis by stating that being more familiar with an iconic symbol system will result in more elaborated graphical representations – reflecting more advanced cognitive processing - and resulting in better test performance. XXXX check this section in order to better understand the kind of statistical analysis you will have to perform –XXXX

Research Method

Participants

90 students participated in this research. They were selected ad random from the total population of freshman studying educational sciences. Participation was a formal part of the course “Instructional Sciences”. Informed consent was obtained prior to experimentation.

Procedure

Students in the training condition received, prior to the experimentation a short introduction about how to develop external graphical representations. During the training the application and the use of external graphical representations were demonstrated. The training presented a variety of graphical representations, but the training was not based on the typology of Wileman (1993).

XXXXXX is the former correct XXXXXXXX

When the study started, the students received materials comparable to those discussed in the second study. In relation to the three experiments, pretest and post

test scores were obtained and twice the students were asked to estimate their perceived *mental effort* as a measure of cognitive load. A researcher, not involved in the research, coded the personal external graphical representations developed by the students. This coding was based on the categorization of Wileman (1993).

XXXX do you have info about intra rater reliability? XXXXX

Results and discussion

Table 4 shows that there is a difference in the frequency each category of external graphical representations appears in the two research conditions.

Table 4. Descriptive results (percentages)

	Without training	With training
Visual symbols	64	56.4
Image-related graphics	1.80	4.44
Concept-related graphics	12.25	6.70
Arbitrary graphics	11.46	13.33
Visual symbol and image-related graphics	2.37	3.11
Visual symbols and concept-related graphics	7.51	15.11
Concept-related graphics and arbitrary graphics	0.40	0.88

In both groups, verbal symbols are used to the highest extent but in different proportions (64% group without training and 56.4% group with training). The table also indicates that the following representation types are observed to a larger extent in the training condition: image-related, arbitrary category, the combination verbal symbols and image-related, the combination verbal symbols and concept-related, the combination concept-related and arbitrary. The concept-related category decreases in this condition to 6.70%. It was expected by the researchers that through training the verbal symbols would decrease and the others would increase. The fact that the concept-related category decreased was not expected and there is no explanation available. XXXX waar is dit op gebaseerd??XXXX

XXX ik snap dit niet, welke gemiddelden heb je vergeleken. Toch niet de percentages???? Je moet uiteindelijk de hypothese toetsen zoals ze hierboven staat: leiden bepaalde hogere proporties van externe representatietypes tot hogere evrwerking en dus significant hogere scores?

To see if there are differences between the two groups an independent t-test was run. Table 5 presents the results. It is clear that there are only significant differences between the groups with the image-related graphics (p=.048), the concept-related graphics (p=.0235) and the combination verbal symbols and concept related graphics (p=.02).

Table 5. Overview of t-test results XXX waarom ineens wel p-waarden opgeven?zie je andere tabllen waar je met ** werk.tXX

	t	Sig.(2-tailed)
Verbal symbols	0.59	0.556
Image related graphics	-1.69	0.100

Concept related graphics	2.02*	0.05
Arbitrary graphics	-0.62	0.54
Verbal symbols and image related graphics	-.48	.64
Verbal symbols and concept related graphics	-2.09*	.04
Concept related graphics and arbitrary graphics	-.70	.49
Image related graphics and arbitrary graphics	.94	.35

Conclusions of the third Study

The results of the third study are ... **MET CONCLUSIE NAAR HYPOTHESE EN UITLEG ERBIJ**

Methodological discussion of the three studies

A number of methodological questions can be raised in relation to the studies and experiments in this research. A first question focuses on the quality of the external graphical representations. Are the results not the outcome of less effective external graphical representations? As explained, much time and effort was invested in the design of the representations, and this by a large team. Secondly, the representations are typical for the approach found in textbooks in the field of psychology and educational sciences. Thirdly, both the static and dynamic representations were designed taking into account the task demands for the students. The inherent structure of the themes were clearly and explicitly depicted or animated in the representations. The retention and transfer question in the post tests also focused on these features. The latter is important since recent studies (see e.g., Schnotz & Bannert, 2003) have proven that non task-appropriate representations do not foster comprehension and mental model construction. Questions about the selection and difficulty level of the specific content of the learning packages can also be put forward. But it was not the first academic year that these contents, although complex in nature, were part of the freshman curriculum in the study programme of the educational sciences.

A typical quality of the CTML-studies of Mayer and his colleagues is the very short duration of the studies. Learning processes limited to 180 seconds are no exception. In the present studies, larger chunks of learning content had to be processed by the students, during a longer period of time. It is possible that the study tasks in the current studies were more demanding than in Mayer's original studies. This could e.g. have affected the results in the third experiment of the second study. Tabbers and others (in press^a) also mention this particular divergence between their studies and these by Mayer as a potential source of inconsistent results.

A critical issue is the fact that individual differences were not taken into account. Since the research population was rather homogeneous in terms of their prior knowledge (freshman), it seemed not useful to take this into account. This might be an issue for future research since Mayer's seventh principle (2001a) refers to the impact of prior knowledge and spatial abilities. He also concludes that external graphical representations might serve different cognitive functions for different subjects. Next to prior knowledge other variables, such as differences in learning styles or spatial abilities, can help to explain the actual research results.

Time on task is an important factor in a lot of researches and analyses. The first research had, as said in the part materials, no time limit. The students could work as long as they wanted on their material. The variable time was not manipulated in the studies, but could play an important role in real life learning situations.

Next, in the three studies the students studied only materials related to the social sciences. This questions whether the findings do not reflect the specific background of these students in this knowledge domain. Future research should consider to present learning materials from different knowledge domains to these students and/or to set up studies involving students of other knowledge domains.

A last remark is about the way the *activation principle* has been operationalized. Students were invited to develop their personal external graphical representations. This is only one way to foster activation as was suggested in the discussion section of study 2. Alternative approaches can be studied, such as collaboration, explaining to others, writing comments next to the learning materials, etc.

Implications for Instructional Design and Future Research

The central research hypothesis of this study questions the generic nature of the CTML design guidelines. The results suggest that instructional designers ought to consider more carefully the nature of knowledge domain. Depending on the knowledge domain there are/are not formal iconic symbol systems available to develop external graphical representations. This affects the extent to which student are familiar with these systems. In the present studies learning materials from the educational sciences have been studied. This knowledge domain clearly differs from e.g., the natural sciences when it comes to the availability of an iconic symbol system to develop (depictive/descriptive) external graphical representations. In the natural sciences it is easier to use depictive representations (derived from real life objects, subjects, situations) and specific symbol sets (e.g. to represent molecule structure, chemical structures).

The results of the present studies suggest that developers of learning materials should pay explicit attention to the nature of the symbolic icon systems in a knowledge domain. As suggested in the three studies, learners could be helped to understand this iconic sign system, develop pre-worked representations or they could be asked to develop representations themselves. Van der Pal and Eysinck (1999) suggest a comparable approach by building up a specific formal language that learners have to master in order to build up graphical representations in the domain of logics.

Building on the methodological remarks about the three studies, characteristics of future research can be outlined. Future research should take into account variables related to individual differences between learners and the knowledge domain in which they study. Alternative activation approaches could be tested; among them research conditions that build on collaborative learning when studying with or without external graphical representations and when developing external representations.

General Conclusions

Although the cognitive theory of multimedia learning is supported by a large number of empirical studies, the results of the studies discussed in the present paper question the extent to which the CTML design guidelines are applicable in all knowledge domains. The paper stresses the importance of the nature of the external graphical representations added to learning materials in the social sciences knowledge domain. Depictive external graphical representations not based on a formal iconic sign system, seem to present learners with difficulties when processing information. The results challenge the CTML but do not question the CTML. The

outcomes of the present research rather present extensions to this theory and extra design guidelines to be taken into account. The results also confirm that more *second generation* CTML-research is needed that considers the unique affordances of external graphical representations in close relation to the active cognitive processing of learners.

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