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Generalizability of the design principles for learning materials derived from the "Cognitive Theory of Multimedia Learning".

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Voorwoord

I want to talk about learning. But not the lifeless, sterile, futile, quickly forgotten stuff that is crammed in to the mind of the poor helpless individual tied into his seat by ironclad bonds of conformity! I am talking about LEARNING – the insatiable curiosity that drives the adolescent boy to absorb everything he can see or hear or read about gasoline engines in order to improve the efficiency and speed of his 'cruiser'. I am talking about the student who says, " I am discovering, drawing in from the outside, and making that which is drawn in a real part of me." I am talking about any learning in which the experience of the learner progresses along this line: "No, no that's not want I want", "Wait! This is closer to what I am interested in, what I need", Ah, here it is! Now I'm grasping and comprehending what I need and what I want to know!"

Carl Rogers, 1989

Hoeveel keer heb ik niet getwijfeld aan het nut van mijn doctoraat en de onderzoeken. Het was een onvoorspelbaar en hobbelig proces waarbij ik dikwijls de minst voor de hand liggende keuze maakte. Meerdere malen had ik het gevoel niet op het juiste spoor te zitten om daarna weer met volle euforie hetgeen ik zocht te vinden. Het moeizaam beslissen, bijschaven, herwerken en doorwerken; een proces, niet altijd even gemakkelijk maar gesteund door verschillende personen werd het toch tot een goed einde werd gebracht.

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Mijn familie, ver en dichtbij, die me op een andere manier steunde. De vele telefoontjes, sms-jes, bezoekjes, het oppassen op onze kleine kapoen, …apprecieer ik zeker. Het maakte het toch iets eenvoudiger om steeds verder te doen. Mama, papa en Sofie, jullie zullen Owen iets minder zien vanaf nu want hij heeft zijn mama voor 100% terug.
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is niet eenvoudig maar daarnaast moesten jullie nog mijn verzoeken, verzuchtingen aanhoren. Jullie luisterende houding, de vele, soms ook flauwe grappen en grollen maakten het voor mij zeer aangenaam werken. Een speciale vermelding voor Ada Peters, onze lector Engels. Haar revisie van mijn teksten, maakten het voor mij eenvoudiger om mijn Engels nog bij te schaven. Ook al was het niet altijd eenvoudig, bedankt Ada!

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Table of contents

Chapter 1

General introduction: the growing impact of multimedia learning materials

Living in a ‘visual’ culture implies that humans in general and learners more specifically, have to consider a wide variety of signs. Wileman (1993) introduces in this context the concept of *visual literacy* and defines this concept as “the ability to ‘read,’ interpret, and understand information presented in pictorial or graphic images” (Wileman, 1993, p. 114). Learners need to master the competence to ‘read’, comprehend and understand these signs. Vygotsky (1987) considers signs to be *psychological tools* that are essential for knowledge construction.

In this dissertation - although the domain of semiotics will not be tackled - the concept of *signs* is central in the theoretical framework and the different empirical studies. *Signs* will be referred to by using the term *iconic symbol signs,* though a broad spectrum of related concepts is used in the literature. Iconic symbol signs comprise a wide variety of visual representations that differ in the way they are strongly, weakly and sometimes even *not* based on realistic representations. This helps to distinguish between two subsets of iconic symbol signs, namely descriptive and depictive representations. Text, formulae or logical expressions are defined as *descriptive iconic symbol signs*. In this case, there are clear conventions about the link between the sign and the related meaning. These conventions are reflected in an iconic symbol sign *system* that forms the base of the representational system (Schnotz, 2002; Schnotz & Bannert, 2003). In contrast, *depictive representations* such as pictures (i.e., more realistic), graphics (i.e., graphical representation of realistic elements) or sculptures do not build on clear-cut iconic symbol sign systems (Goodman, 1976). They convey an integrated piece of information in its entirety; they are realistic image of an object or scene. Goodman (1976) states that wehter a sign is depictive (i.e., representational) depends not on its resemblance to what it denotes but rather upon its own relationships to other symbols in a given system.

Figure 1 gives an example of a depictive iconic symbol sign. The Eiffel tower is represented in a realistic way by this iconic symbol sign. Depictive symbolic signs require that learners are able to link inherent structural features to the content being represented.

Figure 1. A depictive (i.e., realistic) iconic symbol sign of the Eiffel tower.

The ability to read, interpret and understand information presented in pictorial and graphic images will differ on individual level. There are people whom are highly capable and able to read, interpret and understand the presented information correctly. Such persons can be called visual literate while others visual illiterate because they do not posses the ability to read, interpret and understand information. The critical variable in this context is the mastery of iconic symbol signs which can only be achieved through practice (Gilbert, 2005; Gobert, 2005; Roth, 2003; Roth, Ardenghi, & Han, 2005). Prangsma (in press) refers in this case to the learning process that centers on the meaning of the visual representations which is needed. If the iconic symbol system used is unfamiliar to the learners (i.e., they have not mastered the system) they will experience difficulties 'grounding' the sign and processing the information. The example in figure 2 demonstrates how learners might differ in their mastery of symbol signs and how this can affect the correct or adequate interpretation of iconic representations. Most learners acquire mastery of the descriptive iconic sign system (i.e., textual representation) to rightly interpret the meaning of the text *50 km* or *200 km* in a systematic way.

Depending on their prior knowledge about Paris, learners might also have become acquainted with the depictive iconic representation of the Eifel Tower. But, the interpretation of the depictive representation of the arrows, can result in more differences between learners, depending on how their prior knowledge helps them assign meaning of 'from' and 'to' to the arrows. Potential differences between learners become even larger when we look for the meaning of the representation of a woman with a child in the example. There is room for multiple interpretations (e.g., friend, girlfriend, wife, family, mother or grandmother). A mathematical formula, the representation of a chemical structure, the representation of a flow diagram in a programming language, the labelling of electrical circuits, et cetera all of these are typical *iconic symbol systems*.

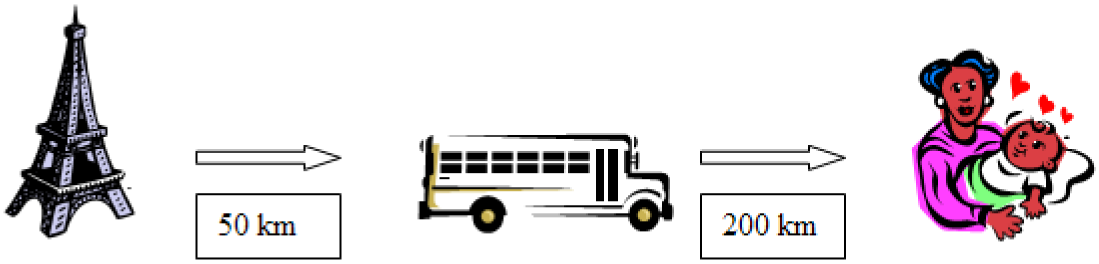

Figure 2. Example of a depictive symbolic sign.

Iconic symbol signs have played an important role in scientific development (Gilbert, 2005; Roth, 2005; Roth & Lee, 2004; Roth, Pozzer-Ardenghi, & Han, 2005) as they have become a central part of the body of scientific knowledge (Gilbert, 2005; Roth, 2005). Being a scientist, in any field, implies the mastery of the related iconic symbol signs. The resulting scientific *visual* literacy is a competence that is central to the mastery of specific scientific knowledge domains. It is therefore no surprise that instructional designers emphasize the importance of the competence in 'reading' and understanding the iconic symbol signs (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, &

Chen, 2002; Lowe, 2003; Lewalter, 2003; Mayer, 2001a, 2003, 2005; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schnotz, 2002; Schwan & Riempp, 2004).

Along with printed books, a variety of media – such as television, computers, the internet – build on a variety of iconic symbol signs (Hegarty, 2004; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schwan & Riempp, 2004). In instructional settings, Houghton and Willows (1987) observe a clear trend to enrich instructional materials with a variety of iconic symbol signs: text, both printed and on the computer or television screen, is augmented with all kinds of graphics (e.g., animated, static, color, black and white) (Bishop & Cates, 2001; Leahy, Chandler, & Sweller, 2003; Lowe, 2003; Schnotz, 2002). Furthermore, also sound is added to the representations. As will be described, the rationale to include these iconic symbol signs is varied and builds on a variety of theoretical and empirical assumptions.

Enriching instructional materials with iconic symbol signs is central to the use of multimedia. Mayer (2001a) defines multimedia as follows: *"Multimedia is the presentation of material using both words and pictures. By words, I mean that the material is presented in verbal form, such as printed or spoken text. By pictures, I mean that the material is presented in pictorial form, such as using static graphics, including illustrations, graphs, photos or maps, or using dynamic graphics, including animation or video."* (Mayer, 2001a, p. 2). Over the years, Mayer's research has evolved into his Cognitive Theory of Multimedia Learning (CTML) (Mayer 2001a, 2001b, 2003, 2005). In this theory, he builds on theoretical assumptions, such as the dual channel assumption, the limited capacity assumption, the active processing assumption to arrive at a variety of principles. Although Mayer uses the concept of *principles*, in this dissertation we approach these principles as *guidelines*, since they will be employed as directives to develop learning materials that have a differential impact on learning achievement. Also in the subsequent chapters that present reports about the different studies set up in the context of this dissertation, we will consistently refer to the CTML-principles by adopting the concept of *guidelines*.

The theoretical base and guidelines laid down by Mayer have been adopted by many researchers to develop instructional materials to improve learners' achievement (Gellevij, van der Meij, de Jong, & Pieters, 2002; Leahy, Chandler, & Sweller, 2003; Martens, Valcke, Poelmans, & Daal, 1996). In addition, a large body of empirical studies has been set up to validate the CTML-guidelines. The results of these studies helped to ground - in a very convincing way - the relevance of the guidelines. Table 1 gives an overview and short description of a set of these studies. Important here, is that most CTML-studies were carried out in the field of the natural sciences (i.e., biology, chemistry, and physics). This brings us to the central research problem of this dissertation, namely whether the CTML is also valid in alternative knowledge domains such as the social sciences?

Table 1. Overview of studies focusing on the impact of applying iconic symbol signs

Topic/knowledge domain	Research	Iconic symbol signs approach
Pumps	Mayer & Anderson, 1991	Depictive: step-by-step drawings of a pump in different states
Brakes	Mayer & Anderson, 1992	Depictive: step-by-step drawings of brakes in different states
Lightning	Mayer, Bove, Bryman, Mars, & Tapangco, 1996	Depictive: step-by-step drawings and animations
Generators	Mayer & Gallini, 1990	Depictive: step-by-step drawings of generators in different states
Lungs	Mayer & Sims, 1994	Depictive: step-by-step drawings of lungs in different states
Soldering	Kalyuga, Chandler, & Sweller, 1999	Depictive: videos of soldering workmen
Chemistry	Kozma, 2003	Descriptive (i.e., chemical formula) and depictive (i.e., set-up of chemical experiment) of process
Ecology	Roth & Bowen, 1999	Descriptive: Cartesian graphs representing cause-effects
Machines	Hegarty & Just, 1993	Depictive: machine functions
Vitamins & minerals	Seufert, 2003	Depictive with chemical set-up and chemical elements in the process
Meteorology	Lowe, 2003	Descriptive: meteorological maps in different states
Geographical time differences	Schnotz & Bannert, 2003[a]	Descriptive and depictive: carpet and circle diagrams
Training program for ‘experimental research’	Tabbers, Martens, & van Merriënboer, 2004	Depictive: diagrams
Introduction to instructional design	Tabbers, Martens, & van Merriënboer, 2004	Depictive: diagrams
Financial decision making	Stern, Aprea, & Ebner, 2003	Descriptive and depictive: mathematical graphs

First order logic	Dobson, 1999	Depictive and descriptive
First order logic	Stenning, 2003	Descriptive (i.e., logical expressions) and depictive with logic tables
First order logic	Dobson, 1995	Depictive: Venn & Euler representations

Outline of the conceptual base of this dissertation

The central research problem of this dissertation introduces a number of key concepts that will be discussed in detail in the next paragraphs: learning with multimedia, guidelines to develop more optimal learning materials. Since we study the validity of the CTML in knowledge domains that differ from Mayer and colleagues, much attention will be paid to the critical mastery of iconic symbol signs in particular knowledge domains. Since we hypothesize that learners might have difficulties with the descriptive and depictive iconic symbol signs used in the social sciences, we put forward a number of additional guidelines that might help to overcome these problems. In these sections we introduce the theoretical base for the activation guideline, the collaboration guideline and the training guideline.

The Cognitive Theory of Multimedia Learning (CTML)

This dissertation's focus on the *cognitive* theory of multimedia learning positions the research in the cognitive perspective towards knowledge processing. The human cognitive structure is considered to resemble an information processing structure (Bransford, 1979; Craik & Lockhart, 1972) based on processes to retrieve, store and process information. Initial theoretical conceptions of the information processing model have been criticized (e.g., Schunk, 2004). A variety of alternative models was put forward: the *dual channel* model where people receive multiple forms of information via two sensory channels (i.e., auditory and visual), and the information received may be words and pictures (i.e., verbal and pictorial), thus being processed through dual coding system (Baddeley, 1992, 1995; Neath, 1998; Paivio, 1978, 1990, 1991), the *multiple channel communication* model in that it involves simultaneous presentations of stimuli through different sensory channels (i.e., sight, sound, touch, etc.) which will provide additional stimuli reinforcement (Broadbent, 1956; Moore, Burton, & Myers, 1996; Shannon & Weaver, 1949), and the *sensory-semantic* model (Nelson, 1979). All these models share the following features: the dual channel assumption, the active processing assumption and the limited capacity assumption.

CTM- assumptions

Table 2 gives a brief overview of the key authors that can be linked to the CTML-assumptions.

Table 2. Research about the assumptions

Assumption	Description	References
Dual channel assumption	Humans apply different channels to process visual or auditory information	Baddeley (1992, 1995) Paivio (1978, 1990, 1991)
Active processing assumption	Humans are actively involved in a continuous selecting-, organisation- and integration process	Barab, Evans, & Back (2000) Bodemer & Ploetzner (2002) Bodemer, Ploetzner, Brüchmüller, & Häcker (2005) Bodemer, Ploetzner, Feurelein, & Spada (2004) Brekelmans, Slegers, & Fraser (2000) Jonassen (2000) Mayer (2001a, 2003, 2005) van Hout-Wolters (2000) Wittrock (1989)
Limited capacity assumption	Humans can only process a limited amount of information in each channel at the same time	Baddeley (1992, 1995) Chandler & Sweller (1991) Kirschner (2002) Paas, Renkl, & Sweller (2003) Sweller (1988, 1994, 2005)

Dual channel assumption

This first assumption has – as stated above - a long history in cognitive psychology. Mayer builds largely on Paivio (1978, 1990 and 1991) and Baddeley (1992, 1995). Central to the assumption is the attention paid to the presentation format of information, also called the modality of the presentation: visual (e.g., text, images), and auditory (Mayer, 2001a, 2005; Mayer & Anderson, 1991; Mayer & Anderson, 1992; Mayer & Moreno, 1998). Mayer builds in this context, clearly on Paivio who stated that textual material is stored in propositional format and images are stored both in visual and propositional format, and on Baddeley who distinguishes two slave systems within the working memory to process either verbal information (i.e., phonological loop) or visuo-spatial information (i.e., visuo-spatial sketchpad). Mayer expands this assumption to distinguish in addition to text and images (i.e., non-verbal), also the auditory presentation of information (i.e., verbal).

Differences in the presentation mode of information are reflected in differences in the sensory mode to process this information. The presentation modality distinguishes therefore between a verbal and a non-verbal mode, each are processed following a separate channel. This channel depends on the sensory mode picked up by either the eyes or ears. This is an extension of the models presented in the literature: the presentation-modality and the sensory modality are indissolubly connected with each other (see Mayer, 2001a, 2001b, 2003, 2005; Mayer & Anderson, 1991, 1992; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer & Sims, 1994).

Active processing assumption

The second assumption states that humans are actively engaged in cognitive processing to construct a coherent mental representation of their experiences. This assumption contrasts with the idea of humans as passive receivers of information and knowledge. Mayer derives from this assumption two implications: the presented materials should have a coherent structure and should provide the learner with guidance to process the information into cognitive structures. If the learning materials lack this, the learner will experience difficulties in processing information while selecting materials (i.e., bringing information to the storage system), organising (i.e., developing structural relations between elements) and integrating processed information with relevant prior knowledge (Mayer, 1989, 1996, 1997, 2001a, 2005; Mayer & Gallini, 1990; Wittrock, 1989).

Limited capacity assumption

The limited capacity assumption states that humans are limited in the amount of information that can be processed along each channel (i.e., the visual channel and the auditory channel). Mayer focuses on the limited capacity of working memory and links this to the concept of cognitive load (Chandler & Sweller, 1991; Sweller, 1988, 1989, 1994, 2005; Sweller & Chandler, 1994). Whereas the capacity of long-term memory is unlimited, working memory (i.e., short term memory) is limited in the extent in which it can process a number of chunks at the same time (Miller, 1956).

Sweller and Chandler distinguish three types of cognitive load: intrinsic cognitive load, the germane cognitive load and the extraneous cognitive load. *Intrinsic cognitive load* is simply linked to the complexity of the information being processed, and cannot be prevented, unless we reduce the complexity of the information. *Germane cognitive load* (Sweller, van Merriënboer & Paas, 1998) is the cognitive load linked to the construction of a cognitive schema. It is this type of cognitive load that instructional designers try to foster and support. In contrast, *extraneous cognitive load* has a detrimental impact and is caused by the way the materials have been presented to the learner. Sweller, van Merriënboer and Paas (1998) give a variety of ways to reduce the extraneous cognitive load and promote germane cognitive load. They refer to graphical representations of the content, and, for example, the use of multimedia (e.g., sound, animations, 3D visualization). Mayer suggests in this context not only to enrich for example, textual information with graphics, but also to exploit the alternative information processing channel that builds on auditory information. This can be done by adding a voice-over to animations instead of presenting text next to the animation (Mayer, 2001a). Other authors present other solutions to cope with cognitive load (Paas, 1992; Sweller, 1989; van Merriënboer & Kirschner, 2007; van Merriënboer, Kirschner, & Kester, 2002): (1) worked examples: learners work with exemplary partially solved problems; (2) 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 their way forward from the given information; (3) 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; (4) emphasis manipulation approach: in the context of a problem, learners are invited to tackle a specific sub-part of the problem; (5) completion strategy: learners complete incomplete solutions; (6) expert-like problem analysis: learners follow a specific set of questions that replicate the type of approach adopted by an expert. In the context of our empirical studies, cognitive load will be considered as an important indicator to study the impact of alternative ways to deal with multimedia in learning materials.

CTML in action

Information processing theory explains how information is processed until it is stored in long term memory. The CTML builds on the same cognitive structure (i.e., working memory, long term memory,…) as visually presented in figure 3 (Mayer, 2001a, 2001b, 2003, 2005). But, taking into account the assumptions explained, parallel processing channels are described. The different modality channels and related memories are distinguished: sensory memory, working memory and long term memory. Information reaches the ears or eyes (via pictures or/and words) through a multimedia presentation. Via ears and eyes, information enters sensory memory where relevant information will be selected to be sent to working memory. Conversion between sound and images is possible (i.e., oral words are also presented as text). In working memory, the organization of the selected images and words result in the construction of pictorial or verbal models. These models are integrated to be linked to prior knowledge in long term memory.

The CTML does not suggest that cognitive processes are linear in nature. An active learner is able to move between memories and models. This *mobility* is a key feature of the model. Also, the two channels to process information cannot be seen as isolated from one another. Presenting ‘oral spoken words’ to a learner does not imply that the processing will be limited to the auditory channel. Oral words can for example, be converted to text (i.e., conversion). This implies that there are interactions between both channels during the processing of the information necessary to develop an integrated and coherent mental model that is linked to prior knowledge.

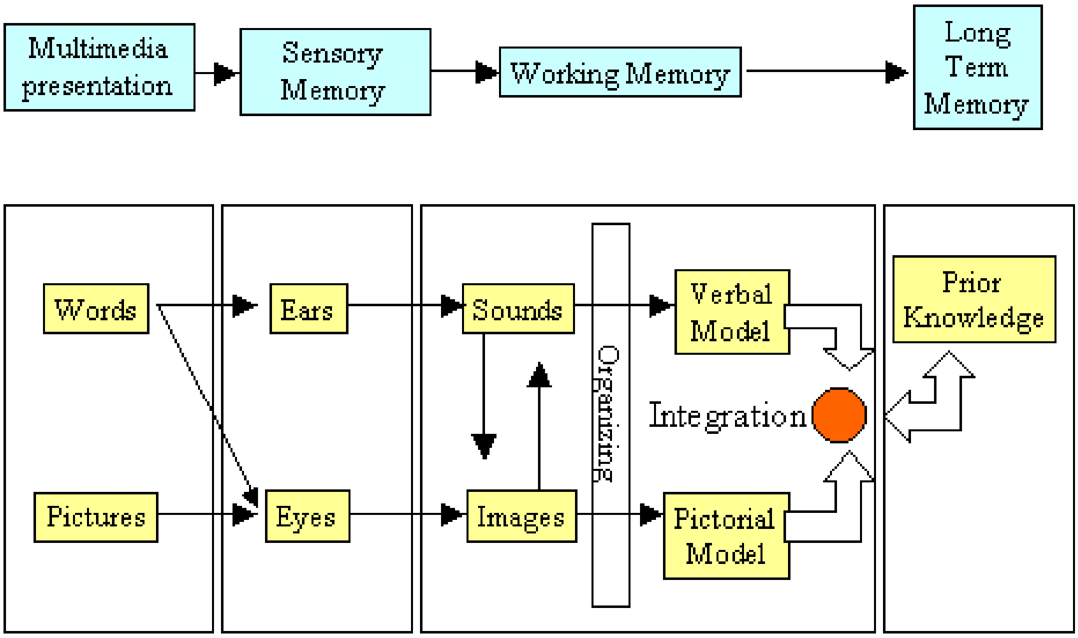

Figure 3. Cognitive theory of multimedia learning (Mayer, 2001a, p. 44).

When learners are presented with complex information to be processed, the presentation format will play a decisive role. At this point we can repeat our earlier discussion about the importance of the mastery of the iconic symbol system that has been applied to develop the presentation. When learners cannot build on their prior knowledge to interpret the descriptive or depictive iconic symbol sign they will experience difficulties that can be labelled as for example, extraneous cognitive load. If this iconic symbol system is unfamiliar to them, they will experience difficulties in 'grounding' the sign and developing an integrated model to relate to prior knowledge. In this dissertation we question whether learners have invariably been able to develop adequate prior knowledge to understand the iconic symbol signs commonly used in certain knowledge domains. In this context we point to a possible mismatch between iconic symbol systems mastered by a learner and the system applied in a particular knowledge representation by the instructional designer or content area expert (De Westelinck, Valcke, De Craene, & Kirschner, 2005). Other authors discuss the same idea, though they do not always link this to the CTML (Dobson, 1995; Goodman, 1976; Lewalter, 2003; Lowe, 2003; Stenning, 1999; Stern, Aprea, & Ebner, 2003). The natural sciences may more easily build on iconic symbol systems that posses a strong relationship with a realistic representation or with clear conventions to direct the representations, something that is less apparent in the other knowledge domains such as the social sciences. We hypothesize that this will affect the selection, processing and organization of information.

The basic CTM- guidelines in the context of multimedia learning

The practical relevance of the CTML is clear when we study the implications for the development of multimedia learning materials (Reimann, 2003). Mayer distinguishes the following multimedia modalities. First, he differentiates between visual representations that build on text, and/or graphics. The latter can be static or dynamic (i.e., animations). This can be linked to the variety of depictive and descriptive iconic symbols discussed above. Although he uses mostly the word animation in defining the guidelines, in the context of this dissertation graphics are primarily the multimedia elements in the learning materials. Secondly, Mayer distinguishes auditory representations that could be oral speech (e.g., narration) or sound in general (e.g. music, background noise,…). When Mayer refers to 'words', this can refer to either a visual and/or auditory representations.

As stated earlier, we approach the CTML-*principles* as *guidelines* that will direct the multimedia design of learning materials in a series of experimental studies. This explains why we consistently will adopt the concept of guidelines instead of principles when discussing Mayers' assumptions related to the CTML-principles.

The guidelines (Mayer, 2001a, 2003) applicable to printed and interactive multimedia learning materials are the: (a) *multimedia guideline*: students learn better from words and pictures than from words alone (Mayer, 2001a, p. 63); (b) *spatial contiguity guideline*: students learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen (Mayer, 2001a, p. 81); (c), *temporal contiguity guideline*: students learn better when corresponding words and pictures are presented simultaneously rather than successively (Mayer, 2001a, p. 96); (d) *coherence guideline*: students learn better when extraneous material is excluded rather than included (Mayer, 2001a, p. 113); (e) *modality guideline*: students learn better from animation and narration than from animations and on-screen text; that is, students learn better when words in a multimedia message are presented as spoken text rather than printed text (Mayer, 2001a, p. 133); (f) *redundancy guideline*: students learn better from animations and narration than from animation, narration and text (Mayer, 2001a, p. 147) and (g) *individual differences guideline*: design effects are stronger for low knowledge learners than for high knowledge learners and for high spatial learners than for low spatial learners (Mayer, 2001a, p. 161) (see Mayer, 2001a, 2001b and 2003 for an overview). Below, the different guidelines are discussed in greater detail.

The multimedia guideline

This guideline indicates that, according to the CTML, learners learn better from words and pictures than from words alone. Words and pictures, presented together, provide learners the opportunity to construct both a verbal and a pictorial model - as discussed above - and make connections between them. This results in a richer integrated mental model. Mayer (2001a) presents a variety of examples and studies that underpin this guideline. A typical example is the comparison of learning from a textual description of a 'pump' (i.e., not the multimedia version) versus the schematic representation of the pump including text describing how it works (i.e., the multimedia version).

The spatial contiguity guideline

The spatial contiguity guideline builds on the fact that learners learn better when corresponding words and pictures are presented in close proximity of one another. When corresponding text and graphics are kept near each other, it will be easier to retain both the text and the graphics together in working memory. Mayer (2001a, 2005) puts forward much empirical research to ground the effectiveness of this guideline (Mayer, 1989; Mayer & Moreno, 1998; Mousavi, Low, & Sweller, 1995). They refer in this context to the split attention effect, a more general but comparable notion to the spatial contiguity guideline. The split-attention effect is defined as the learning impairment caused when learners must make integrated models on the basis of disparate information (Ayres & Sweller, 2005; Chandler & Sweller, 1991; Sweller & Chandler, 1994). To reduce the cognitive load caused by the split attention effect, a variety of instructional design ideas have been studied that build on the spatial contiguity guideline (Paas, 1992; Sweller, 1989; van Merriënboer, Kirschner, & Kester, 2002). When two representations are removed from one another, learners have to cope with more *space*. Covering this space is possible but at a *cost*. Imagine a book that explains in detail how lightening works during a storm on one page, while a set of graphic static representations ‘depicting’ this same phenomenon is found on the next page. The same set of related information is presented twice, but by means of different representations. Both the graphical and textual representation can be considered as separate routes for delivering information to the learner. But in this case learners have to use extra cognitive resources to look for the corresponding words and graphics since they are not presented near each other. The CTML states that in order to reach an integrated mental model, all information should be represented in such a way that learners are helped to build connections between different representations. Connections will cognitively *cost* more when the *space* is too large between alternative representations. This puts a higher load on spending cognitive resources and results in additional increased cognitive load (Brünken, Plass, & Leutner, 2003; Brünken, Steinbacher, Plass, & Leutner, 2002; Grace-Martin, 2001; Mayer & Moreno, 2003; van Bruggen, Boshuizen, & Kirschner, 2003; van Bruggen, Kirschner, & Jochems, 2002).

Temporal contiguity guideline

Similar to limited *space* also *time* is a scarce source when having to process complex information. The temporal contiguity guideline states that learners perform better when corresponding words and pictures are presented simultaneously and not successively. It can be argued that a successive presentation of a narration and a graphical representation of how lightning evolves can be beneficial. The same information is repeated. But, building on the dual channel assumption, Mayer argues that (1) both modalities can be processed at the same time, and that (2) simultaneous presentation fosters integration of the visual and verbal representations in working memory. In contrast, he argues that a consecutive presentation leads to an *overload* in the working memory, because learners need to bring the first representation back to it while processing the second one. Mayer reintroduces in this context again the split attention effect, already discussed. The time delay in the presentation of both knowledge representations causes a detrimental split attention effect. Mayer and his colleagues present convincing empirical evidence to support this guideline (see e.g., Mayer & Anderson, 1991, 1992; Mayer & Simms, 1994; Moreno & Mayer, 1999).

Coherence guideline

Extra and irrelevant material distracts the learners’ attention and do not lead to better learning. Learners learn better when irrelevant material is not included in a multimedia presentation. It causes extraneous cognitive load and can be labelled as *extraneous material*. The CTML states that extraneous material is *stealing* cognitive resources in working memory. It is possible that (1) attention is diverted from relevant information, (2) information organisation process is interrupted and/or (3) learners build mental models related to inappropriate information. Mayer (2001a) distinguishes three coherence guidelines. Firstly, learning is compromised when interesting but irrelevant words and pictures are added to a multimedia presentation. Extra material can make a presentation more attractive but will divert learner attention (e.g., anecdotes about volcano eruptions to a description of the mechanisms behind a volcano eruption). Mayer refers to this as seductive details (Garner, Brown, Sanders, & Menke, 1992; Garner, Gillingham, & White, 1989; Harp & Mayer, 1997, 1998). Secondly, learning is impeded when interesting but irrelevant sounds and music are added to a multimedia presentation (e.g., adding poetic background music to a representation of a Norwegian fjord). Third, learning is improved when unnecessary words are removed from multimedia presentations. Abstracts are for example, more effective than extensive and elaborated texts. Empirical research supports the claims in relation to these varying interpretations of the coherence guideline (Mayer, Bove, Bryman, Mars, & Tapangco, 1996).

Modality guideline

Students learn better from animation and narration than from animations and on-screen text; that is, students learn better when words in a multimedia message are presented as spoken rather than printed text (Mayer, 2001a, p. 133). This guideline is a reformulation of the dual channel theory (Baddeley, 1992) or dual coding theory (Paivio, 1978, 1990, 1991). The working memory, according to Baddeley, is built up by the visuo-spatial sketch pad and the phonological loop. The latter is used to process auditory material and the sketch pad is used to process visual material. Presenting visual and auditory information fully exploits the cognitive capacities of both channels. Presenting only visual information (i.e., a graphic and a printed text) implies that we have to process the text and graphical representations at the same time which will result in cognitive overload in the visual channel. Mousavi, Low, and Sweller (1995) built on this modality guideline in their research. They see the modality guideline as increasing cognitive capacity when both the auditory and visual working memory can be used. Representing information according to such a mixed mode will increase the effective activity in working memory. In close analogy, Bishop and Cates (2001) discuss different theories to support the use of sound in multimedia learning and state that sound plays a role in information processing (i.e., gaining attention, consolidating information, elaborating visual stimuli). Kalyuga, Chandler, and Sweller (1999), Mayer (1997, 2001a), and Mayer and Moreno (1998) present a fully documented set of studies to underpin the impact of the modality guideline.

Redundancy guideline

Students learn better from animations and narration than from animation, narration and text (Mayer, 2001a). CTML contradicts with this guideline a current practice for example, adding on-screen text to narrated animations. Based on the limited capacity assumption, adding text causes an overload in the visual channel of the cognitive system. Adding on-screen text to a narrated animation will therefore result in poorer learning. This guideline has been largely confirmed by empirical research (Leahy, Chandler, & Sweller, 2003; Mayer, Bove, Bryman, & Mars, 1996; Moreno, & Mayer, 2002; Kalyuga, Chandler, & Sweller, 1999). It can be argued that learners might get the opportunity to choose a preferred optimal representation mode when offered a variety of representations. This guideline can be linked to the particular literature about learning styles that point at preferences for knowledge representations. We do not enter this research field in the present dissertation, but refer to the related literature (see e.g., Dunn & Dunn, 1978; Dunn, Dunn, & Price, 1975; Entwistle, Hanley, & Hounsel, 1979; Gardner, 1953; Kolb, 1976; Riding, Grimley, Dahraei, & Banner, 2003; Witkin, Moore, Goodenough, & Cox, 1977). But as will become clear in the next section, we nevertheless partly deal with this issue, when discussing individual differences.

Individual differences guideline

The guidelines have a stronger impact in learners with low-prior knowledge and high-spatial abilities. CTML enters in this way the discussion about individual differences and partly the discussion arena about *styles*. In a growing number of studies, Mayer is able to underpin his assumptions (see discussion in Mayer 2001a). It is hypothesized that high-spatial learners have an advantage over low-spatial learners. High-spatial learners possess the cognitive capacity to mentally integrate visual and verbal representations from effective multimedia presentations whereas low spatial learners need to make available more cognitive capacities to hold visual representations in working memory. The latter leads faster to insufficient capacity remaining for the integration of both visual and verbal representations. A second critical individual difference is related to the level of prior knowledge. High-knowledge learners are able to use their prior knowledge to compensate for lack of guidance in the presentation whereas low-knowledge learners do not have that possibility. It is comparable to the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003). Instructional techniques that are highly effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners. Since the conception of the CTML and the definition of the first seven CTML-guidelines, Mayer and his colleagues, but also other researchers have advanced additional guidelines (Mayer, 2005). In the context of this dissertation, we start from the initial set of seven guidelines, but build on more recent CTML-studies when these new guidelines prove to be of relevance for the studies reported here.

The validity of the guidelines in the social sciences

The crucial role of mastering the iconic symbol system

Together with other researchers (see e.g., Cox, 1999), we state that the potential positive impact of adding multimedia to learning materials is affected by the degree to which learners' understand the semantics of the representational system (i.e., iconic symbol system). Although we do not discuss semiotics in detail, related research plays an important role. The empirical findings of Lowe (2003) suggest that learners more easily extract information from representations with clear visual-spatial characteristics, such as structural coherence and distinctive appearance (e.g., closely related to reality). Novices attend to visually salient aspects of the representations that are not relevant, whereas experts look at the relevant aspects. They do not extract the same level of information from representations that lack these qualities. He concludes, in a study on learning meteorology from weather maps, that students do not extract the major meteorological concepts from weather maps and that their mental models are "likely to be incomplete, fragmentary and of limited value in building high-quality mental models of weather map dynamics" (Lowe, 2003, p. 174). He stated that novices attend to visually salient aspects of illustrations that are not relevant to solving a problem, whereas in contrast, experts look at relevant, though less salient features. Indicators for the critical role of *the mastery* of the iconic symbol systems can also be found in the study of Schnotz, and Bannert (2003) that had to conclude that adding pictures to text is not beneficial in general, and that it can even have negative effects on learning because they can interfere with the construction of mental models. In a more explicit way, Dobson (1999) found that the impact of multimedia representations is influenced by the difficulties learners experience in interpreting the representations. He also determined that students actually prefer lexical parts in the learning materials to diagram-representations.

Iconic symbol system

In the introductory part of this chapter, the concepts *iconic symbol sign* and *iconic symbol system* were defined. Signs and sign systems lie at the base of a scientific knowledge domain. Mastery of the symbol system is referred to with a number of concepts. Some authors consider it to be part of *scientific literacy:* the competence to understand and present information as sketches, photographs, maps, plans, charts, diagrams and other (non-)textual representations (Aldrich & Sheppard, 2000; Gilbert, 2005; Gobert, 2005; Roth, Pozzer-Ardenghi, & Han, 2005). Wileman (1993) applies in this context to the concept of *visual thinking* which he defines as the ability to conceptualize and present thoughts, ideas and data as pictures and graphics, replacing much of the verbal words we now use to communicate. A more focused definition is given by Kozma and Russel (2005) when they refer to *representational competence* in the knowledge domain of chemistry. According to them, this is the set of skills and practices that allow a person to reflectively use a variety of iconic symbol signs, visualizations, individual and together and act on phenomena in terms of underlying, perceptual entities and processes. In this dissertation, we adopt the term *scientific literacy* when referring to the mastery of the iconic symbol signs and systems.

In scientific literacy, a distinction can be drawn between five competency levels (see Table 3). At a first and basic level, the symbolic sign is looked upon as an iconic depiction of the concept or phenomenon. At a second level, symbolic skills play a prime role. The representation is expected to be more than a depictive one, but also a descriptive, symbolic representation is adhered to. But the learner does not always apply this symbolic sign correctly (i.e., she/he makes semantic and/or syntactic errors). The third level states that there is a more appropriate syntactic use of iconic symbol signs. Learners apply the iconic symbol system in a rather personal way that is not always 100% accurate. This evolves into the fourth level, where in addition the semantic use of formal iconic symbol signs is now mastered. When the learner is able to use the iconic symbol signs correctly and make connections between different representations, the fifth level is reached. At this level, a learner can use the representations reflectively and rhetorically, which may be considered to be the expert or master level (Dori & Belcher, 2005; Kozma & Russel, 2005). To reach the master level, it is important to be exposed to a broad array of types of symbolic sign systems. This implies getting opportunities to sufficiently practise the above mentioned skills. The research, discussed in this dissertation, questions whether learners, when presented with learning materials in e.g., the domain of the social sciences, have attained a sufficiently high mastery level of the implied iconic symbol system that lies at the base of a multimedia representation.

It is not possible, in the context of this dissertation, to study the wide variety of approaches adopted within the social sciences. Therefore, we will consistently study the design of learning materials in the field of the educational sciences.

Table 3. Levels of scientific literacy

Level 1	Representation as an isomorphic, iconic depiction.
Level 2	Early symbolic skills. The person is familiar with the formal iconic symbol signs system but uses it without regard to syntax and semantics.
Level 3	Syntactic use of formal iconic symbol signs.
Level 4	Semantic use of formal iconic symbol signs.
Level 5	Reflective, rhetorical use of iconic symbol signs.

The mastery of iconic symbol signs and systems implies structuring and grounding

The previous section points at critical cognitive processes that interfere with the cognitive processing of multimedia learning materials. Roth (2005), Roth, Pozzer-Ardenghi and Han (2003) and Gilbert (2005) refer in this context to the process of reading iconic symbol signs as a semiotic activity where three different elements interrelate with each other: the *sign*, the *referent* and the *interpretant*. Signs are the material traces that refer the reader to something other than themselves (i.e., the referent). Material traces can be in this case pictures, graphs and so forth. Signs can build on an iconic symbol system. Interpretants are commentaries on the sign, definitions of the sign in its relation to the referent object. Semiosis is the process through which interpretants are produced. The relation between signs and referents is arbitrary and has to be consistent with culture (i.e., rules and conventions). The semiotic process, influenced by culture (i.e., rules and conventions), has to be acquired by novices. In addition, signs can never be understood without being related to other surrounding signs.

Reading signs implies two processes: the structuring process and the grounding process.
When corresponding text and graphics are put close together, it will be easier to hold both the text and the graphics together in working memory. Mayer (2001a, 2005) puts forward a number of empirical researches to ground the effectiveness of this guideline (Mayer, 1989; Mayer & Moreno, 1998; Mousavi, Low, & Sweller, 1995). They refer in this context to the split-attention effect, a more general but comparable notion to the spatial contiguity guideline. The split-attention effect is defined as the learning impairment that is caused when learners are required to make integrated models based on disparate information (Ayres & Sweller, 2005; Chandler & Sweller 1991; Sweller & Chandler, 1994). To reduce the cognitive load caused by the split-attention effect, a variety of instructional design ideas have been studied that build on the spatial contiguity guideline (Paas, 1992; Sweller, 1989; van Merriënboer, Kirschner, & Kester, 2002).

Coping with a weaker mastery of the iconic symbol system: alternative guidelines
Bringing together CTML-guidelines and the critical discussion about the conditional mastery of the iconic symbol system underlying multimedia representations is helpful to position the next section of this chapter. As explained below, two studies to replicate the CTML findings in the social sciences and other domains revealed inconsistencies with the original CTML findings of Mayer and colleagues. The discussion of the inconsistent results introduced the need to formulate alternative guidelines to counter or compensate for the weak mastery of the iconic symbol system applied in the multimedia representation. Due to space limitations in the research articles brought together in this dissertation, we take the opportunity to present a systematic and detailed overview of the theoretical base that grounds these alternative guidelines in this introductory chapter.

The activation guideline
The activation guideline implies those learners are explicitly invited to focus on the multimedia representations and the iconic symbol system underlying the development of the representation. Though positioned as an alternative and extra guideline, the activation guideline is consistent with basic assumptions of the CTML; more particularly the active processing assumption. This implies that learners select, process, and organize information in working memory in an automatic way in view of the development of mental models and the integration in long term memory. CTML expects that well designed learning materials

promote active information processing (Mayer, 2001a, 2001b, 2003, 2005). Activation could also be considered as a way to reduce cognitive load (Paas, 1992; Sweller, 1989; van Merriënboer, Kirschner, & Kester, 2002). In contrast to the CTML-assumptions, several studies reveal that learners often remain passive when presented with multimedia representations (Bodemer, Ploetzner, Bruchmüller, & Häcker, 2005). This may be due to the degree of unfamiliarity/lack of acquaintance of the learner with the iconic symbol system being applied. Instructional interventions that promote the active creation of personal multimedia representations are expected to counter this. This would force them to develop and use a personal iconic symbol system. We can link the potential of this guideline to a large body of empirical evidence. Marzano, Pickering, and Pollock (2001) present a meta-analysis of studies that tested the active construction of non-linguistic representations (NLR) and report effect sizes varying from 0.5 to 1.3. Though these studies do not always build on the CTML, the studies share the cognitivist assumptions that NLR support learners in processing information and foster the development of mental models within the working memory and/or help to integrate these mental models into the long term memory. Other research has suggested other ways to engage participants actively in the learning process: working with concept maps (Novak, 1989) or presenting learners with pre-worked examples (Gerjets, Scheiter, & Catrambone, 2006; Paas & van Gog, 2006; Paas, van Merriënboer, & Adam, 1994; Sweller, 1989, 2006; Sweller & Chandler, 1991; Van Gerven, Paas, van Merriënboer, Hendriks, & Schmidt, 2002; van Gog, Paas, & van Merriënboer, 2006; van Merriënboer, Kirschner, & Kester, 2003). Activation is not to be deemed part of a dichotomy between learners that are either completely active or completely passive. On the basis of a literature review, Van Meter and Garner (2005) structure a variety of activation levels along a continuum. At one end, multimedia representations are developed by educational designers and presented as such to learners (i.e., no activation). At the other end, multimedia representations are constructed by individual learners themselves (i.e., full activation). In-between both extreme types of activation, the authors position 'worked examples' of multimedia representations that consist of semi-finished designs and where learners are invited to complete the partially elaborated visual representations.

The collaboration guideline

Distributed cognition theory (Hutchins, 1995) states that in individual cognitive processing, when corresponding text and graphics are placed in proximity to one another, it will be easier to maintain both the text and the graphics together in working memory. Working together in a collaborative setting can be seen as a way to improve individual learning processes. In a collaborative setting iconic symbol signs are seen as communicative tools (Reimann, 2003; Suthers & Hundhausen, 2001; Teasly & Rochelle, 1993; Van Drie, Van Boxtel, Jaspers, & Kanselaar, 2005). The rationale for introducing collaborative learning in instructional settings is mostly linked to changing views about learning and the nature of knowledge. This is often referred to as social constructivism (Jonassen, Lee, Yang, & Laffey, 2005; Van der Linden, Erkens, Schmidt, & Renshaw, 2000). In this dissertation, we do not take this broad theoretical perspective, but concentrate on the implications of collaboration in view of working with iconic symbol signs (i.e., multimedia) in learning materials. During the collaborative process, learners must make an effort to coordinate their language and activity toward shared understanding (Driscoll, 2000; Greenwood & Thompson Fillmer, 1999; Joyce, Calhoun, & Hopkins, 2000; O'Donell & King, 1999; Van der linden, Erkens, Schmidt, & Renshaw, 2000). Hence, learners in collaborative settings explicitly have to negotiate meaning, share and compose joint views and construct shared knowledge. Learners can in this context develop a shared representation of the knowledge elements (Beers, Boshuizen, Kirschner, and Gijselaers, 2005, 2007).

The training guideline
Since familiarity and/or acquaintance with an iconic symbol system is considered a key factor that influences the adequate processing of knowledge, the training guideline introduces an alternative approach. This guideline thus introduces training in the active use of the iconic symbol system. As explained, we can build on a five-step model to direct the development of the conditional prior knowledge to interpret correctly iconic symbol systems and reach sufficient mastery (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005; Roth, 2003; Roth, Pozzer-Ardenghi, & Han, 20005; Wileman, 1993). At a basic level, the learner interprets the symbols as an iconic depiction that evolves along the subsequent three additional stages to a final stage where reflective use of the iconic symbols signs becomes possible. The fifth level is considered mastery - the expert level - the goal for scientists or student-scientists (Dori & Belcher, 2005; Kozma & Russel, 2005). It is hypothesized that training learners in using iconic symbol systems is beneficial for learning performances. If learners are taught how to deal with an iconic symbol system, cognitive load might decrease and active processing towards the construction of mental models and integration with prior knowledge is stimulated. This may result in an increase in learning outcomes. Gilbert (2005) states in addition that the related mastery will improve through relevant experience. This is confirmed by Kozma and Russel (1997) when they emphasize the importance of developing these related competences. Other authors come to the same conclusions (Bowen & Roth, 2002; Brna, Cox, & Good, 2001; Roth, Bowen, & Maciotra, 2005; Roth, Pozzer-Ardenghi, & Han, 2005).

The empirical studies in this dissertation

The adoption of a design-based research approach
In what follows we try to explain how the studies were designed and conducted. It gives a clear view on how the studies followed each other during three consecutive academic years. The consecutive studies reported in this dissertation have been set up as steps in a design-based research cycle. While there is an ongoing debate about what constitutes design-based research, we build on the definition of Wang and Hannafin (2005, p.6): "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and

practitioners in real-world settings, and leading to contextually-sensitive design principles and theories”. Drawing on the available literature, these authors stress five basic characteristics of design-based research: “Pragmatic, Grounded, Interactive, Iterative and flexible, Integrative, and Contextual” (ibid, p.7). Design-based research is therefore a methodology that tries to examine learning in naturalistic contexts that are designed for and can be changed by the researcher. This research helps produce new theories and inspires practices for learning and teaching in naturalistic settings (Barab & Squire, 2004; Cobb, diSessa, Lehres, & Schauble, 2003). Researchers using this methodology systematically adjust various aspects of the environment so that it can be seen as a type of experimentation that allows the testing and generation of theory in naturalistic contexts (Brown, 1992). Clearly the presented studies took the design based research cycle into account and incorporated the findings of earlier studies, repeated earlier features, added new alternative interventions, and partly replicated earlier findings. As a start, the CTML-guidelines were researched in a replicating research in the social sciences. Seeing that the results of that research were not as expected, it made us revert to the literature to look for new and additional guidelines. The adoption of additional guidelines (i.e., activation, collaboration, training) is an example of how new instructional approaches were considered in the consecutive studies. The consecutive studies share a number of features to enable the development of a consistent empirical body of knowledge about the impact of the original CTML and alternative guidelines. First, the consecutive studies were set up in the same context of a university course for university freshmen. All the studies were set up in a naturalistic quasi-experimental setting during three consecutive academic years. Each study started with an overall prior knowledge test about the content of the learning materials to be studied. Additional information about background variables of the participants was obtained. Research participants were randomly assigned to specific experimental or control conditions. In each research condition, participants studied subsequent sets of learning materials (three to four sets). Each set started and ended with the administration of a knowledge and application test. Knowledge tests studied the retention of information by learners; application tests went a step further by testing how much of the knowledge the learners could transfer or apply in similar situations. Twice during the study of the sets of learning materials, participants were asked to score their perceived cognitive load. In the literature, measurement of cognitive load is mainly based on the learners’ subjective report of their perceived mental effort. This results in a subjective cognitive load score. The scale applied in these studies was developed by Paas, Renkl, and Sweller (1994). Participants write down the amount of effort they needed to study the materials on a scale varying from 0 to 9. Use of this type of scale is reported to have a high reliability (Cronbach's α) of .90 to .82 (Paas, 1992, Paas et al., 1994). Building on the particular guidelines, the multimedia elaboration, and the way learner(s) processed the learning materials enriched with the multimedia representations, differed in the experimental conditions of the individual studies.

Research questions and overview of the dissertation research

Building on the theoretical background explained above, the following research questions determined the design of five empirical studies that are reported in this dissertation:

1. Can we generalize the design guidelines for designing learning materials derived from the Cognitive Theory of Multimedia Learning which have been gathered primarily from the natural sciences to other domains of learning? (first and general research question)
2. Do multimedia learning materials in the domain of the social sciences result in higher performances of participants on knowledge and application tests and result in lower levels of perceived cognitive load compared to participants who have not been offered multimedia learning materials?
3. To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load influenced by the mastery level of the used iconic symbol systems?
4. To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load influenced by the active engagement of the participants in the learning process?
5. To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load in a collaborative setting influenced by active engagement?
6. What is the impact of training in the use of an iconic symbol system on the learning performance of participants and the levels of perceived cognitive load?

Table 4. Overview of the research questions in the different chapters

	RQ1	RQ2	RQ3	RQ4	RQ5	RQ6
Chapter 1						
Chapter 2[a]	X	X				
Chapter 3[b]	X	X	X			
Chapter 4[c]	X			X		
Chapter 5 [d]	X				X	
Chapter 6 [e]	X					X
Chapter 7	X	X	X	X	X	X

RQ = Research Question

[a] Manuscript published in *Computers in Human Behaviour*.

[b] Manuscript submitted for publication in *Contemporary Educational Psychology*.

[c] Manuscript submitted for publication to *Instructional Science* and partly published as a chapter in L. Verschaffel, E. De Corte, G. Kanselaar, & M. Valcke (Eds.). *Designing powerful learning environments to promote deep conceptual and strategic learning in major curricular domains* (pp. 213-232). Leuven, Belgium: Studia Paedagogica - Leuven University Press.

[d] Manuscript submitted for publication in *Teaching in Higher Education*.

[e] Manuscript submitted for publication in *Learning and Individual Differences* and partly published as a chapter in L. Verschaffel, E. De Corte, G. Kanselaar, & M. Valcke (Eds.). *Designing powerful learning environments to promote deep conceptual and strategic learning in major curricular domains* (pp. 213-232). Leuven, Belgium: Studia Paedagogica - Leuven University Press.

Table 4 indicates the link between the different studies reported in the dissertation and the six research questions.

Chapter two

Chapter two reports the set-up and results of the first study, designed to test the impact of developing learning materials according to CTML-guidelines, but in the social sciences. Do learners, studying social science learning materials enriched with multimedia according to the CTML-guidelines, achieve significantly higher scores as compared to learners who have not been offered this multimedia elaboration? In this study, the focus is on research question one. It was expected that learners will not benefit (i.e., attain higher performances on knowledge and application question) from multimedia learning materials in knowledge domains different from traditional CTML-knowledge domains. We build in this study on the assumption that the social sciences knowledge domain requires the adoption of a different iconic symbol system to develop the multimedia elaboration by instructional designers. Earlier CTML-research was mostly set up out in the natural sciences where visual representations are either depictive in nature and/or representations are based on established descriptive iconic symbol systems (e.g., formulas, chemical symbols, flow charts, et cetera).

This study involved the entire population of freshmen enrolled in the Pedagogical Sciences program of the faculty of Psychology and Educational sciences at the Ghent University (Belgium) more specifically in the course ‘Instructional Sciences’ (N=190) during the first semester of the academic year 2002-2003. It was set up as an integrated part of the course. Students were randomly assigned to six different conditions in order to individually study three sets of learning materials. As explained above, learners started by solving a prior knowledge test. After studying the content of a subset of learning materials, they solved a post test consisting of knowledge and application questions.

Chapter 2 is based on the following published article: De Westelinck, K., Valcke, M, De Craene, B., & Kirschner, P. (2005). Multimedia learning in social sciences: limitations of external graphical representations. *Computers in Human Behavior, 21*, 555-573.

Chapter three

The study reported in chapter three is an extension of the study in chapter two. While the latter study focused on studying learning materials in the social sciences, the participants in the former studied multimedia learning materials in two different knowledge domains. Participants studied multimedia learning materials related to ‘Instructional Sciences’, a field they are expected to be acquainted with and knowledgeable in and multimedia learning materials in the natural sciences, a field that they would be less acquainted with and less knowledgeable in. This implies that we expect them to be more familiar and/or acquainted with the iconic symbol system in the former as compared to the latter. Care was taken to present and develop materials of comparable levels of difficulties. The research question focuses on the hypothesized differences in being acquainted with the underlying iconic symbol systems that will affect learning performance level. In other words, does the level of acquaintance with a certain iconic symbol system influence the performances of learners? This study was set up during the academic year 2005-2006. The entire population of 286 freshmen enrolled in the Pedagogical Sciences program of the faculty of Psychology and

Educational sciences of Ghent University (Belgium) participated in the study. A quasi-experimental design was adopted in which students were assigned randomly to one of the six conditions. In each condition, sets of learning materials were developed and presented for the two different knowledge domains (i.e., natural sciences and educational sciences). Three different multimedia elaborations were presented to the students: text only (T), text with visual representations (T+V), and visual representations enriched with audio (V+A). In line with the approach adopted in the first study, the participants received a package consisting of a pretest, subsets of learning materials, and a posttest to be solved after each subset of learning materials. Additionally, their perceived cognitive load was measured on two occasions. Chapter three is based on an article, submitted to *Contemporary Educational Psychology*.

Chapter four

Chapter four goes a step further than the approach in the previous chapter. Building on the less consistent results found in the earlier studies about the impact of the traditional CTML-guidelines on knowledge acquisition, an alternative guideline is added to the research design: the activation guideline. The central question in this study is whether adding activation to the learning process contributes added value, and thus results in higher performances of learners when studying multimedia elaborated learning materials. This was referred to as the third research question above. Again all freshmen enrolled for the course 'Instructional Sciences' participated in the study (N=219), during the academic year 2003-2004. Consistent with the approach adopted in the earlier studies, participants received a package consisting of a prior knowledge test, subsets of learning materials enriched with alternative multimedia elaborations and posttests. The different (multimedia) elaborations considered in the study are text only (T), text and visual representations (T+V), text and pre-worked examples of visual representations (T+PW) and text and the active development of the visual representations by the participants (T+D). Both the T+PW and T+D condition build on the hypothetical impact of the activation guideline, though they differ in the degree of activation.

Chapter four is based on an article, submitted to *Instructional Science*. The results have also partly been incorporated in De Westelinck, K. & Valcke, M. (2005). The impact of external graphical representations in different knowledge domains: Is there a domain specific effect? In L. Verschaffel, E. De Corte, G. Kanselaar, & M. Valcke (Eds.). *Designing powerful learning environments to promote deep conceptual and strategic learning in major curricular domains* (pp. 213-232). Leuven, Belgium: Studia Paedagogica - Leuven University Press.

Chapter five

Chapter five reports on a study in which a second alternative guideline is tested, namely the collaboration guideline. This study focuses on the fourth research question: Does collaboration in processing multimedia learning materials and the underlying iconic symbol system have an impact on learning performance? Again all freshmen enrolled for the course

'Instructional Sciences' participated in the study (N=217), during the academic year 2004-2005. Participants were randomly assigned to one of the four research conditions. The different multimedia elaborations considered in the study are text only (T), text and visual representations (T+V), text and the active development of the visual representations by the participants (T+D) and text and the active development of the visual representations after training (T+D after training. Depending on literature, it was hypothised that learners studying multimedia learning materials will attain higher performances (i.e., scores on knowledge and application question) and report a lower level of perceived cognitive load when they are more actively and collaboratively engaged in the processing of the learning materials.
Chapter five is based on an article submitted to *Teaching in Higher Education*.

Chapter six

Chapter six is partly a replication of the third study reported on in chapter four in which the activation guideline was scrutinized. However, in this study this is done in combination with the training guideline. Both the third and fifth research question are central in this study: What is the potential impact on learning performance when learners are trained and/or activated in the use of iconic symbol systems that underpin the design of multimedia learning materials? Consistent with the earlier studies, all freshmen enrolled in the course 'Instructional Sciences' participated in the study (N=218), during the academic year 2003-2004. Participants were randomly assigned to one of four research conditions: text only (T), text and visual representations (T+V), text and activation in the use of visual representations (T+A), and text and activation in the use of visual representations after receiving training (T+T+A). Depending on theoretical information it was expected that learners who receive training will perform significantly higher on knowledge and application questions and report lower levels of cognitive load when actively engaged in the processing of the learning materials compared to learners who were not actively engaged (i.e., studied learning materials with ready-made visual representations).
Chapter six is based on an article submitted to *Contemporary Educational Psychology*. Preliminary results, reported in this chapter, have also partly been incorporated in: De Westelinck, K., & Valcke, M. (2005). The impact of external graphical representations in different knowledge domains: is there a domain specific effect? In L. Verschaffel, E., De Corte, G. Kanselaar, & M. Valcke (Eds.). *Designing powerful learning environments to promote deep conceptual and strategic learning in major curricular domains* (pp. 213-232). Leuven, Belgium: Studia Paedagogica - Leuven University Press.

Chapter seven

The final chapter pulls together the research results obtained in the studies reported in the previous chapters. An integrated overview of the research findings is presented and conclusions emerging from the separate studies are discussed. Theoretical and practical implications are discussed and directions for future research are presented.

Table 5. Overview of the guidelines studied in the subsequent studies and reported in the different chapters

Research/ chapter	Multimedia guideline	Spatial contiguity guideline	Coherence guideline	Individual differences	All guidelines are taken into consideration	Knowledge domains	Activation guideline	Collaboration guideline	Training guideline
Research 1/ Chapter 2	X	X	X						
Research 2/ Chapter 3					X	X			
Research 3/ Chapter 4					X		X		
Research 4/ Chapter 5					X		X	X	
Research 5/ Chapter 6					X		X		X

Conclusions

In this introductory chapter we presented the theoretical framework, developed in view of the different experimental studies. In this framework, the CTML plays a central role. This theory is seen as an ‘answer’ to the growing importance and impact – living as we do in a visual culture - of multimedia representations in learning materials. Such a growing impact of a visual culture has influenced the design of learning materials by adding multimedia that are based on a wide variety of iconic symbol signs. A key hypothesis, driving the central research problem presented in this introductory chapter is that the inclusion of multimedia implies that learners need to develop/master a new competency: visual literacy. This means that learners have to develop a mastery of the iconic symbol system or systems used within a specific domain to develop in-depth understanding of the representations used in those scientific knowledge domains. The need to take this competency into account illustrates the role of instructional designers when choosing/developing adequate multimedia representations. In this context, the Cognitive Theory of Multimedia Learning of Mayer has proven to be an important frame of reference. In addition, the CTML has helped define a number of concrete guidelines for the development of multimedia learning materials. Building on empirical research, a number of limitations of the original CTML-guidelines have been noted. This introduced the need to define and ground alternative guidelines, especially when multimedia learning is set up in the social sciences knowledge domain. This brings us back to the focal point of this dissertation: the critical mastery of the iconic symbol system that lies at the base of the multimedia elaboration of learning materials.

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Chapter 2[*]

Multimedia learning in social sciences: limitations of visual representations.

Abstract

In a series of six experimental studies, each consisting of three sub-studies, the central question was researched whether adding visual representations to printed or electronic learning materials improves knowledge and application scores. These studies research the degree of generalizability of Mayer's cognitive theory of multimedia learning (CTML) to the knowledge domain of the social sciences. The research hypotheses build on the assumption that this knowledge domain differs in the way instructional designers are able to develop adequate visual representations. Earlier CTML-research was mostly carried out in the field of the natural sciences where visual representations are depictive in nature and/or where representations can be developed from existing or acquired iconic symbol systems. The results indicate that alternative guidelines might need to be considered when learners study learning materials with visual representations that reflect low levels of repleteness and do not build on an iconic symbol system previously mastered or acquired by the learners. The research results reveal that studying this type of representation does not result in higher test performance and does not result in lower levels of mental load.

Multimedia Learning in Social Sciences: Limitations of visual representations

The Cognitive Theory of Multimedia Learning (CTML) posited by Mayer (2001a) presents a clear framework to direct instructional design of both printed and interactive multimedia materials. The power of CTML and these guidelines is not only linked to a clear theoretical base, but also builds on the empirical evidence presented by Mayer, his colleagues, and other researchers. Consequently, instructional designers find the theory theoretical and practical appealing. But daily teaching experience of the authors of the present article, responsible for freshman courses in the knowledge domain of educational sciences, is not in line with CTML. Students appear to have difficulties in coping with visual representations such as schemas, tables and graphs. 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.

Through testing the CTML-guidelines in another subject domain the question of extending or generalizing the cognitive theory of multimedia learning is raised. Printed and computer multimedia learning materials are used to test the original CTML-based research

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hypotheses, but do this in the context of alternative hypotheses that are put forward to explain results/expectations not completely in line with CTML-guidelines.

Basic Assumptions and Guidelines of CTML

Mayer’s theory of multimedia learning (2001a, 2003) is based on three central assumptions. The *dual channel assumption* states that two separate channels are used to process information (see Figure 1). A first channel processes sounds in working memory, resulting in verbal models. A second channel is used to process images, resulting in pictorial models. The construction of both verbal and pictorial models can be influenced by prior knowledge retrieved from long term memory. Both are integrated into one coherent structure to be stored in long term memory. The second CTML-assumption focuses on the processing of all sensory input: the *active processing assumption*. This implies that the learner is actively engaged in processing information and makes an effort to construct coherent mental models. Typical cognitive processes involved in the latter are selecting, organizing and integrating. The third assumption is the *limited capacity assumption*. This implies that learners are limited in the amount of information they can process simultaneously along each channel.

These three theoretical assumptions are related to comparable notions in the literature. The dual channel assumption is also found in the working memory model of Baddeley (1992) and Chandler and Sweller (1991), the multiple channel communication model of Moore, Burton, and Myers (1996), the dual-coding theory of Paivio (1978, 1991), the sensory-semantic model of Nelson (1979) and the multiple-channel communication theory of Broadbent (1956), Shannon and Weaver (1949) and others. The second assumption about limited capacity is related to the ‘cognitive load theory’ (CLT) of Sweller and colleagues (1988, 1989, 1994) who also tried to describe and explain the difficulties learners meet when dealing with complex knowledge domains. The active processing assumption is central to most cognitive theories and is, for example, explicitly mentioned by Wittrock (1989).

The practical relevance of CTML is evidenced by the definition of guidelines for multimedia learning materials and is as such most clearly directed towards the instructional designer community (Reimann, 2003). The guidelines (formulated as stated in the book Multimedia Learning by Mayer) are applicable to printed and interactive multimedia learning materials: (a) the *multimedia guideline*: learners benefit more from words and pictures than from words alone, (b) the *temporal contiguity guideline*: learners perform better when corresponding words and pictures are presented in close temporal proximity (e.g., simultaneously) instead of successively, (c) the *spatial contiguity guideline*: learning is fostered when words and pictures are represented close to one another on a page or screen, (d) the *coherence guideline*: learning performance is better when extraneous sounds, words, pictures are excluded, (e) the *modality guideline*: learners learn more from animation enriched with audio (narration) than from animation enriched with printed text, (f) the *redundancy guideline*: learners perform better when presented with animation and narration instead of animation and narration combined with printed text when the printed text matches the narration, and (g) the *individual differences guideline*: all guidelines have a stronger impact with low-prior knowledge learners and learners with high-spatial abilities (see Mayer, 2001a, 2001b and 2003 for an overview).

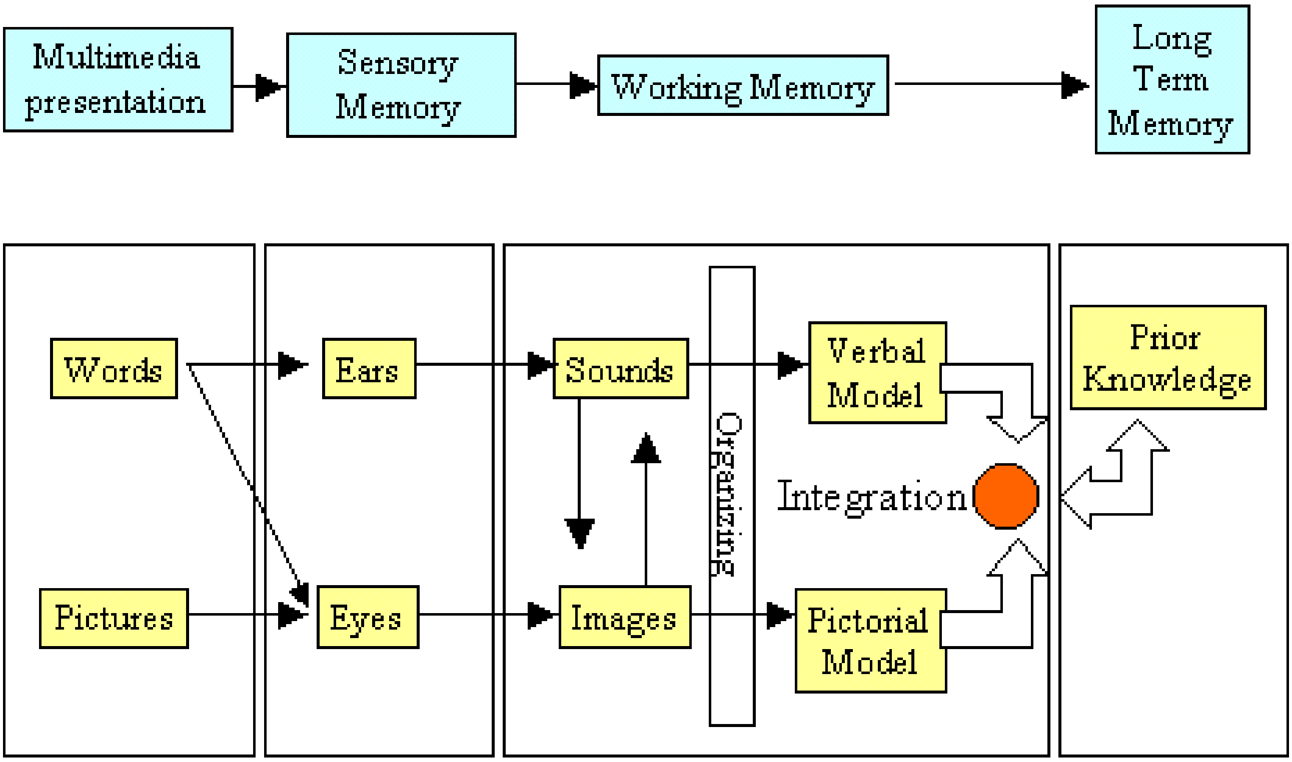


Figure 1. The cognitive theory of multimedia learning (Mayer, 2001, p.44).

Next there is the phenomenon called *expertise reversal*: what is optimal for low prior knowledge learners is suboptimal for experts and vice versa (Kalyuga, Ayres, Chandler & Sweller, 2003) Mayer stresses the generic nature of these guidelines (2001a, p. 193). He, states that they can help to explain why instructional designers, such as Tufte (1983, 1990) stressed to enrich text with graphical representations such as tables, graphs, diagrams and charts. The research here questions the generic nature of the guidelines by focusing on some problems related to the nature of iconic symbol signs in a particular knowledge domain.

Nature and Impact of Types of visual representations

There is a long tradition in theoretical and empirical research about visual representations in learning materials (see Anglin, Towers, & Levie, 1996 for an overview). This article focuses in particular on the CTML to study the theoretical and empirical impact of visual representations in learning materials. Although CTML-research has given a lot of proof that using the guidelines developing learning materials result in higher performance on knowledge- and application tests recent CTML-related research presents inconsistent results about the impact on student performance. Goldman (2003), in a recent review of visual representations, asks in this context for a *second generation* of research. She considers Mayer’s work as *first generation* research focusing on generic guidelines to understand consistencies in the processing of verbal and visual information. The *second generation* should be helpful for understanding the affordances of visual representations in view of task demands, the active processing of learners, the support learners receive in processing the learning materials and low or high prior knowledge. The research presented here is a contribution to this second generation since it focuses on the affordances of visual representations in view of the active processing by learners in a specific domain. It especially questions whether learners are sufficiently acquainted with the base of the iconic symbol system as reflected in visual representations. The question is also related to the nature of knowledge domains.

Mayer differentiates between verbal and pictorial representations, noting that verbal representations require more mental effort to be processed by the learner. Pictorial representations are considered more original modes of knowledge representation. Mayer (2001a) states that pictorial representations are more intuitive and closer to visual experience. Presenting both text and pictures invokes deep learning because the learner is required to develop both verbal and pictorial mental representations and connections between them.

Schnotz and Bannert (2003) elaborated on this theoretical distinction between verbal (descriptive) and pictorial (depictive) representations in an alternative way. In their view, *descriptive* representations such as text, formulae or logical expressions build on the use of symbols related to content via conventions. An important part of the symbol system is used to reflect relationships between the symbols (e.g., verbs and prepositions). Of importance for the present study is that such descriptive representations like printed text on paper or a screen can build on available and/or acquired *iconic symbol systems*. Goodman (1976) notes that *depictive* representations such as pictures, graphics, or sculptures do not build on such iconic symbol systems. Each type of depictive representation possesses inherent structural features that have very specific associations with the content represented. The example in Figure 2 demonstrates how a learner has to interpret that the arrows to the left and right of the bus indicate the distance is to and from the two destinations. In other words, the learner has to know or learn and understand these associations between the structural features of the representation and the content represented. In this example an iconic symbol system is available to understand a part of the representation (i.e., what 50 km or 200 km means), but to understand the specific meaning of the arrows, most learners will have to rely on prior knowledge to assign the meaning ‘from’ and ‘to’. Most learners will interpret this part of the depictive representation analogously and also that the tower is the Eiffel tower in Paris. As to the meaning of the woman with the child, there is room for multiple interpretations (e.g., friend, girlfriend, wife, family, mother or grandmother). In this example, alternative representations of this part of the representation will not result in a lack of understanding of the overall content of the representation.

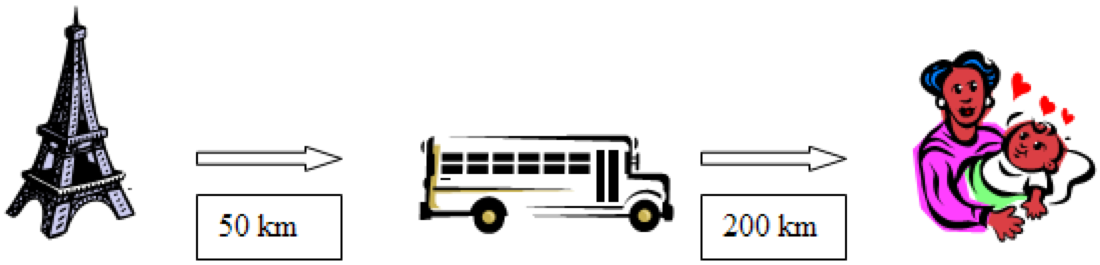


Figure 2. Example of a depictive visual representation consisting of elements with high and low repleteness.

The fact that learners need to be acquainted with the iconic symbol system used to develop an external graphical representation is the core of this study. Mayer, as explained earlier, would state that the depictive representation of the Eiffel tower and the woman with child are more intuitive and closer to visual experience than the descriptive representations of distances and directions. Learners are expected to process these depictive representations much faster than they would the descriptive ones. In other words, the learner builds a pictorial model with the correct visual-perceptual relationships. At question here is whether learners have sufficient and adequate prior knowledge to understand the depictive representations. The implication is that prior knowledge influences mastery of the iconic symbol system at the base of the representations and that learners could have more difficulties and/or need more time to develop mental models when confronted with new or unknown iconic symbol systems. There can, in other words, be a mismatch between the iconic symbol system of a learner and the iconic symbol system used in the representations which can cause learners to experience more difficulties and/or need more time to develop mental models when confronted with new or unknown iconic symbol systems. Goodman (1976) calls this a low level of *repleteness*, an index of the number of elements that are significant for the learner. Low repleteness implies a limited similarity to the realistic representation, which in turn implies a high cognitive load when confronted with such depictions and thus little space for learning processes. If this is the case, the benefits of adding iconic symbol signs to achieve meaningful learning, which are typical for Mayer's studies, may not be found here. Stenning (1999) and Dobson (1999) qualify this via the variable *expressiveness*. Lower levels of expressiveness lead to more room for interpretations. Lowe (2003), for example, indicates that novices are easily captivated by the perceptually salient features of the displays and miss in this way the underlying guidelines and relationships. Stern, Aprea, and Ebner (2003) come to comparable conclusions finding that students who do not understand the fundamental concepts of graphs are prevented form noticing the key relationships in them. Also Lewalter (2003) points to the critical problem of students who do not succeed in identifying relevant information presented in iconic symbol signs. Consequently, Goldman stresses the fact that representations "are only successful in improving learning from text to the degree that learners are able to interpret the cues" (Goldman, 2003, p. 240). Mayer and Gallini (1990) indicate, for example, that learners might experience difficulties in identifying the relevant information presented in an illustration.

Table 1. The knowledge domain and type of visual representations in CTML-research

Topic/knowledge domain	Research	Iconic symbol signs approach
Pumps	Mayer & Anderson, 1991	Depictive: step-by-step drawings of a pump in different states
Brakes	Mayer & Anderson, 1992	Depictive: step-by-step drawings of brakes in different states
Lightning	Mayer, Bove, Bryman, Mars, & Tapangco, 1996	Depictive: step-by-step drawings and animations
Generators	Mayer & Gallini, 1990	Depictive: step-by-step drawings of generators in different states
Lungs	Mayer & Sims, 1994	Depictive: step-by-step drawings of lungs in different states
Soldering	Kalyuga, Chandler, & Sweller, 1999	Depictive: videos of soldering workmen
Chemistry	Kozma, 2003	Descriptive (i.e., chemical formula) and depictive (i.e., set-up of chemical experiment) of process
Ecology	Roth & Bowen, 1999	Descriptive: Cartesian graphs representing cause-effects
Machines	Hegarty & Just, 1993	Depictive: machine functions
Vitamines & minerals	Seufert, 2003	Depictive with chemical set-up and chemical elements in the process
Meteorology	Lowe, 2003	Descriptive: meteorological maps in different states
Geographical time differences	Schnotz & Bannert, 2003[a]	Descriptive and depictive: carpet and circle diagrams
Training program for 'experimental research'	Tabbers, Martens, & van Merriënboer, 2004	Depictive: diagrams
Introduction to instructional design	Tabbers, Martens, & van Merriënboer, 2004	Depictive: diagrams
Financial decision making	Stern, Aprea, & Ebner, 2003	Descriptive and depictive: mathematical graphs

First order logic	Dobson, 1999	Depictive and descriptive
First order logic	Stenning, 2003	Descriptive (i.e., logical expressions) and depictive with logic tables
First order logic	Dobson, 1995	Depictive: Venn & Euler representations

A review of the research literature from the perspective of iconic symbol sytems reveals two important issues. First, there are *inconsistencies* in the way visual representations have been studied. Not all the studies make use of depictive representations (see Table 1). Mayer's original studies of (2001a, 2003) about lightning, pumps, and brakes are clear examples of depictive studies. But other studies, however, focus on more descriptive since they build on the use of symbols related to content by means of convention. These studies add visual representations such as flowcharts, formula editors, mathematical symbol sets, chemical formulas, and chemical reaction representations. This may be the source of inconsistencies in the findings of these studies about the CTML-guidelines. Second, most studies have been set up in the natural sciences. But, knowledge domains differ in their use of iconic symbol systems. Recent CTML-studies set up in other knowledge domains can provide a significant extension of CTML. The central hypothesis of the present research is that learners in the social sciences will experience difficulties with depictive visual representations as opposed to descriptive visual representations (e.g., text), due to interpretation difficulties of the iconic symbol system used to develop these representations. Whereas the natural sciences can more easily build on intuitive (or acquired) consensual iconic symbol signs, this is less apparent in the social sciences. These difficulties are expected to affect selection, processing and organizational processes of the learners. Due to less unequivocal (i.e., unambiguous) iconic symbol signs and the less known or unfamiliar iconic symbol systems used, students are more likely to experience higher cognitive load. As a result of this increased cognitive load learners will develop less effective mental models and the deep-level learning predicted by Mayer, will hardly occur. Consequently, knowledge and/or application is expected to equivalent or lower than when the depictions are absent. If this is the case, then CTML-guidelines might be extended by taking the nature of the knowledge domain and/or the mastery of symbol system by learners into account.

Research

In a series of six separate experiments the basic tenets of CTML were tested as to their validity in the social sciences and how CTML might be extended.

Methods

Participants

In total 190 freshmen studying educational sciences at a Flemish university participated in this study. They represent the entire population of first-year students in the second semester 2002-2003. Participation was a formal part of the course 'Instructional Sciences'. Informed consent was obtained from all students prior to experimentation.

Procedure

The studies were set up during two sessions, organized during two consecutive weeks. Students were randomly assigned to the experimental conditions. The groups were formed by selecting the students as they appeared on the alphabetical tuition list. There were six experiments consisting of three sub-studies each focusing on a theme, related to the selected learning content (see Materials). No students were assigned to the same condition in successive sessions. Each experimental condition was organized in a different room. Students, at the start of each session, received a study package consisting of (a) a prior knowledge test, (b) a specific elaboration of the learning materials to be studied, and (c) a posttest of mastery of the complex knowledge elaborated in the learning materials (knowledge and application). After the second sub-study of each session, students were invited to indicate the cognitive load experienced during study. No time limit was set for studying the materials and/or completing the tests. The study package of students in computer conditions (i.e, to test the guidelines with dynamic representations) only consisted of pretests, cognitive load measures and the posttest for each sub theme in the session. Students in these conditions studied the multimedia materials in a computer room.

The answers to the knowledge and application questions were scored by three independent researchers not involved in the current study. The scoring was based on a scoring checklist that provided an optimal answer to each individual question. A score was given depending on the number of elements in a student's answer. To facilitate interpretation of the test scores, all scores were standardized, with a maximum score of 20 for each pre- and post-test.

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: (a) the conceptual differentiation between behavior, mental activities, learning strategies and learning styles, (b) Curry's typology to differentiate between learning style as a personality trait, an information processing style or an instructional preference, (c) Dunn and Dunn's learning style approach, (d) Kolb's learning style approach, (e) Witkin's learning style model, and (f) Vermunt's learning style model. This learning content is complex and at a high difficulty level for freshman.

To guarantee the optimal design of the representations, Mayer's recommendations were taken into account (2001a, p. 191-193). He states that the signs should have a potentially meaningful structure (a cause-effect relationship, interdependencies or hierarchies) and depict the different states of the complex structure. Building on these guidelines, the authors and a group of 20 fourth-year psychology students taking a course in instructional design, developed a series of possible visual representations for each theme from which the authors selected and finalized the multimedia representations for each learning styles theme. Special care was taken when representing the structural relationships in the body of knowledge (such as dependent upon, consisting of, different from, follows from, affects, contains, et cetera). Figure 3 depicts a page of printed learning materials with visual representations about Kolb's learning style approach. It is clear from the example that the visual representations do not build on a formal and/or existing iconic symbol system. Moreover, the approach is similar to the typical iconic symbol signs found in psychology and educational sciences textbooks. For the design of the dynamic visual representations, computer animations were developed that were equivalent to those in the printed learning materials. The animations show, step by step, the build up of the representations incorporated in the printed materials. The students controlled the speed of the animations by clicking on the *continue* button on the screen.

Instruments

A pretest and posttest were presented to the students which consisted of knowledge and application questions. Knowledge questions measure what students remember about a topic (e.g., What are the different operational approaches that Vermunt incorporates in his approach towards learning styles?). Application questions are related to problem solving. They test the deeper understanding of the content by having students explain phenomena that cannot immediately be retrieved from memory (e.g., What is the relationship between cognitive style and personality in Witkin's approach?). The analysis section reports the test results separately for each type of question, along with a total test score.

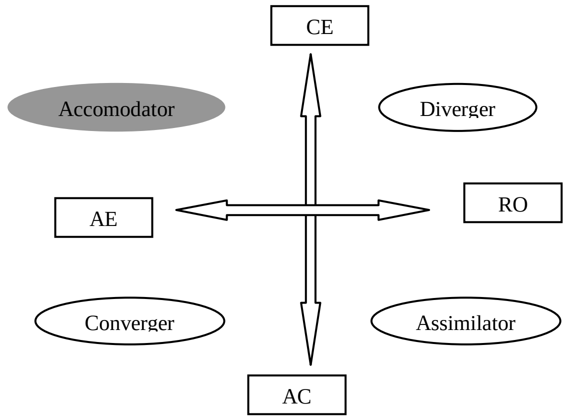
In the literature, measurement of cognitive load is mainly based on the learners' subjective report of their perceived *mental effort*. This results in a subjective cognitive load scale (Paas, Van Merriënboer, & Adam, 1994) in which students note the amount of effort they experienced on a scale varying from 1 (very, very, very easy) to 9 (very, very, very difficult). Application of this kind of scale results in high reliability measures (Cronbach's α) of .90 to .82 (Paas, 1992, Paas et al., 1994).

Statistical analysis

All analyses are based on the comparison of mean test scores of students in the different conditions. Analysis of variance is applied after testing for homogeneity of variances. A significance level of $p<.01$ is used as the critical value. In case of statistically significant differences in mean posttest scores, Cohen's d is calculated to determine effect size (Thalheimer & Cook, 2002).

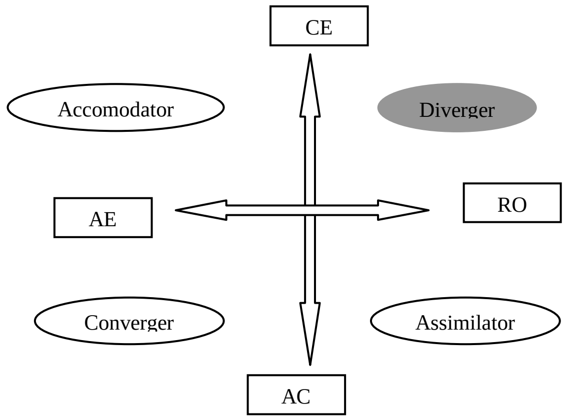
Type 1 Accomodator

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.

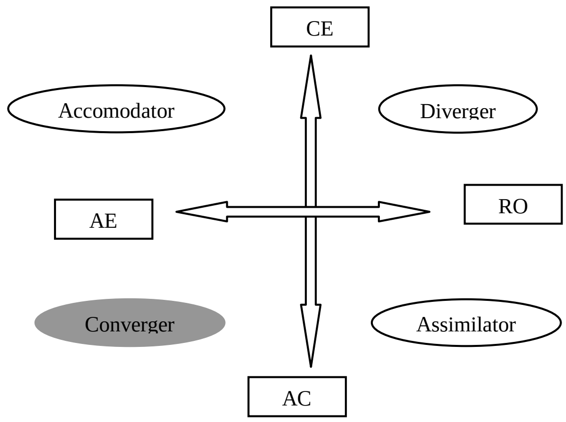


Figure 3. Example of learning materials to test hypothesis three related to the coherence guideline.

Results

Table 2 summarizes the descriptive statistical analysis results, based on the test scores of students, in the different conditions. The results of the pretest scores are not reported since all students obtained a zero-score for both the knowledge and application questions in this test.

This clearly indicates that the knowledge content was completely new for the students and of a high difficulty level.

The value of the multimedia guideline is tested twice via the experiments set up in both research sessions. The results in Table 2 are clear. With the exception of the posttest scores in relation to the first sub-study, students studying learning materials with no visual representations always attain a higher mean posttest score. Analysis of variance (see Table 3) reveals that these differences are significant for the second sub-study. The effect sizes are very large to large: $d = 1.12$ for the application test and $d = .95$ for the total posttest score in relation to the specific learning styles content.

The analysis of the descriptive results in relation to spatial contiguity shows that the majority of the conditions where illustrations are not spatially integrated result in higher post-test scores than when this is the case. The differences in scores for the application question and the total posttest in the first sub-study are significant. In both cases, this results in a medium effect size of $d = .72$.

Analysis of the results in relation to the coherence guideline suggest that students studying learning materials consisting of summaries with visual representations perform better on posttest questions, though none of the differences are significant.

With respect to computer based (multimedia) learning materials the condition where animations are enriched with audio should, according to the modality guideline, lead to higher performance than the condition where the animation is enriched with screen text. The descriptive results in the sub-studies do not support this, though none of the differences found are significant.

The posttest scores of students studying non-redundant learning materials, that is animation with narration and without additional text are mostly higher, but here too the differences are not significant.

Finally, since each of the conditions employed build on different applications of CTML-guidelines it is possible to see whether there are differences in cognitive load in favor of CTML-designs. There were no significant differences, with the exception of conditions presenting alternative designs based on the coherence guideline. The cognitive load for students studying the most coherent learning materials was significantly higher with a medium effect size of $d = .72$.

Table 2 (part 1). Mean scores and standard deviation for the knowledge, application and total scores in each experiment and for each sub study

Central hypothesis in the experiment		Multimedia guideline				Spatial contiguity guideline				Coherence guideline			
		Text without representations		Text with external representations		Representations not integrated		Integrated representations		Summaries with representations		Expanded with illustrations	
Session 1		*M*[a]	*SD*	*M*[b]	*SD*	*M*[e]	*SD*	*M*[f]	*SD*	*na*[i]		*na*	
Sub 1	Knowledge	17.50	5.27	19.43	2.01	20.00	0.00	20.00	0.00				
	Application	9.03	5.18	10.14	6.36	17.79	4.12	14.43	5.25				
	Total	13.26	4.34	14.78	3.34	18.89	2.06	17.21	2.63				
Sub 2	Knowledge	19.26	2.65	18.66	2.70	19.41	2.52	19.23	2.15				
	Application	6.80	3.61	3.14	2.99	7.20	3.30	6.86	4.55				
	Total	12.14	2.68	9.70	2.33	12.44	2.32	12.16	2.97				
Sub 3	Knowledge	7.78	7.60	6.00	8.12	15.88	6.57	15.42	6.57				
	Application	11.48	3.42	11.04	4.56	11.95	6.09	12.57	5.55				
	Total	10.00	3.88	9.03	4.58	13.52	5.02	13.71	4.78				
	Mental load	5.17	2.03	-[j]	-[j]	4.61	2.19	3.97	2.05				
	Session 2	*M*[c]	*SD*	*M*[d]	*SD*	*na*		*Na*		*M*[g]	*SD*	*M*[h]	*SD*
Sub 4	Knowledge	14.97	4.38	14.40	4.70					13.83	2.97	11.69	4.62
	Application	13.99	6.23	12.13	7.38					12.79	5.60	11.39	4.99
	Total	14.52	4.24	13.35	5.38					13.36	3.58	11.56	3.45
Sub 5	Knowledge	7.20	2.59	6.04	2.18					7.25	10.12	4.44	2.37
	Application	6.66	4.51	6.13	3.68					6.97	4.18	7.13	4.15
	Total	6.97	2.32	6.07	1.59					7.13	6.55	5.51	2.04
Sub 6	Knowledge	19.80	1.00	18.00	4.56					16.76	6.46	16.28	6.91
	Application	12.26	6.85	11.46	8.05					10.15	8.44	7.44	7.99
	Total	16.57	3.09	15.20	3.47					13.92	5.42	12.49	5.58
	Mental load	5.56	1.32	5.00	1.95					5.95	1.87	4.86	1.74

[a]*N = 36.* [b]*N* = 35. [c]*N* = 25. [d]*N* = 25. [e]*N = 34.* [f]*N* = 35. [g]*N* = 44. [h]*N* = 43.

[i]Not applicable. No experiments were set up to test this specific hypothesis during this session.

[j] Due to a layout error in the package of the students for the condition with visual representations, an insufficient number of students replied to the question to estimate their mental load.

Table 2 (continued). Mean scores and standard deviation for the knowledge, application and total scores in each experiment and for each sub study

Central hypothesis in the experiment		Modality guideline				Redundancy guideline			
		Animation with narration		Animation with printed text		Animation with printed text and narration		Animation only with narration	
Session 1		*M*[a]	*SD*	*M*[b]	*SD*	*na*[e]		*na*	
Sub 1	Knowledge	19.04	2.46	19.80	1.00				
	Application	11.92	6.33	11.40	4.90				
	Total	15.42	3.16	15.60	2.53				
Sub 2	Knowledge	19.23	2.88	18.93	3.15				
	Application	5.77	3.37	6.40	3.68				
	Total	11.54	2.62	11.77	2.52				
Sub 3	Knowledge	7.31	7.77	5.60	7.68				
	Application	10.25	5.41	11.99	3.33				
	Total	9.08	3.85	9.44	3.44				
	Mental load	4.58	1.74	4.30	1.89				
Session 2		*na*		*na*		*M*[c]	*SD*	*M*[d]	*SD*
Sub 4	Knowledge					13.14	3.98	14.34	3.93
	Application					8.40	5.28	7.05	4.25
	Total					10.95	3.47	10.98	2.38
Sub 5	Knowledge					4.44	2.31	4.62	2.58
	Application					3.86	3.92	5.89	5.10
	Total					4.21	2.09	5.12	1.54
Sub 6	Knowledge					16.00	1.65	15.77	7.20
	Application					7.73	5.86	7.95	9.98
	Total					12.46	8.96	12.42	6.19
	Mental load					5.68	1.65	5.61	2.19

[a]*N* = 26. [b]*N* = 25. [c]*N* = 25. [d]*N* = 26.

[e]Not applicable. No experiments were set up to test this specific hypothesis during this session.

Table 3. Overview of ANOVA results

		Multimedia		Spatial contiguity		Coherence		Modality		Redundancy	
Session 1		*F (1,69)*	*p*	*F (1,67)*	*p*	*na*[a]		*F (1,49)*	*p*	*na*	
Sub 1	Knowledge	4.09	.05	[c]	[c]			2.07	.16		
	Application	.69	.42	8.74	**.004***			.11	.74		
	Total	2.73	.10	8.74	**.004***			.02	.88		
Sub 2	Knowledge	.87	.35	.09	.76			.12	.73		
	Application	21.56	**.00***	.13	.72			.41	.53		
	Total	15.49	**.00***	.18	.67			.10	.75		
Sub 3	Knowledge	.91	.34	.08	.77			.62	.43		
	Application	.21	.65	.19	.66			1.90	.17		
	Total	.93	.34	.02	.88			.13	.72		
	Mental load	-[b]	-[b]	1.60	.21			.28	.60		
Session 2		*F (1,48)*	*p*	*na*		*F (1.85)*	*P*	*na*		*F (1,49)*	*p*
Sub 4	Knowledge	.20	.66			6.60	.02			1.17	.28
	Application	.93	.34			1.52	.22			1.01	.32
	Total	.73	.40			5.70	.02			.00	.98
Sub 5	Knowledge	2.92	.09			3.13	.08			.06	.80
	Application	.21	.65			.03	.86			2.52	.12
	Total	2.60	.11			2.38	.13			3.17	.08
Sub 6	Knowledge	3.71	.06			.11	.74			0.2	.90
	Application	.14	.71			2.36	.13			.01	.94
	Total	2.18	.15			1.49	.23			.00	.98
	Mental load	1.40	.24			7.99	**.006***			.01	.91

[a]Not applicable. No experiments were set up to test this specific hypothesis during this session. [b]Due to a layout error in the package of the students for the condition with external representations, an insufficient replied to the question to estimate their mental load. [c]Since students in both conditions obtain the maximum score for the knowledge question in relation to this first sub study, no *F*-value can be calculated. * $p < .01$.

Discussion

The results of the studies presented here do not present an unequivocal answer to the question of CTML-guidelines are generalizable to different domains. On the one hand, the results raise serious questions (i.e., statistically significant differences in the non-CTML direction) by some of the assumptions of CTML-guidelines, especially those based on the multimedia, spatial contiguity, and modality guidelines. On the other hand, the lack of significant positive results in line with the CTML-assumptions opens the door to alternative explanations.

One noteworthy result was the significant differences in posttest scores indicating that studying text without representations sometimes results in higher performance. This is clearly in contrast with the original CTML-hypothesis and suggests that learners have problems when studying from visual representations because of inadequate experience with or knowledge of the iconic symbol system used. Support for this can be found in a number of research studies. Cox (1999), for example, states that the impact of graphical versus textual representations might be affected by the degree to which learners' understand the semantics of the representational system. This is also consistent with the findings of Lowe (2003), namely that subjects best extract information from representations where there are clear visual-spatial characteristics, such as structural coherence and distinctive appearance (e.g., closely related to reality). They do not extract information from representations that lack these qualities. He concludes in a study of learning meteorology from weather maps that students do not extract the elements of major meteorological importance from weather maps; knowledge structures (mental models) are "likely to be incomplete, fragmentary and of limited value in building high-quality mental models of weather map dynamics" (Lowe, 2003, p. 174). Support is also found in Schnotz and Bannert (2003) who conclude that adding pictures to text is not generally beneficial, and that it can even have negative effects on learning because they may interfere with the construction of mental models. Finally, Dobson (1999) found that the impact of representations is influenced by the difficulties the students have to interpret the diagrams. He also determined that students actually prefer lexical parts in the learning materials as compared to diagram-representations.

A specific result was the fact that spatially contiguous integration of visual representations in printed learning materials does not result in higher posttest scores as compared to learning materials with non-contiguous representations. In both conditions, students apparently experience difficulties with the specific depictive representations. The contiguity of the representations to the text appears to hinder the students whereas in the non-contiguous conditions they can focus on a consistent textual (sentential) representation.

The effect of different aspects of the impact of representations on cognitive load could be tested in five of the experiments. At the descriptive level, there are only small differences in reported cognitive load by the students in the different conditions with a significant difference in only one condition, namely that students studying the more coherent learning materials experience higher cognitive load – a finding that is clearly not in line with CTML-based theory. Tabbers et al. (2004) also report inconsistent results as to the impact of visual representations on cognitive load.

The practical implications of these findings are clear. Instructional designers may not be able to simply 'apply' CTML-guidelines to learning materials in a knowledge domain where no unequivocal iconic symbol system is available to students and where representations have a low level of repleteness. This does not imply that the use of the CTML-guidelines is not recommended, but rather that caution is prescribed in other domains.

Methodological issues

A number of methodological questions can be raised in relation to the experiments in this research. A first question focuses on the quality of the external graphical representations: Are the results due to poor external graphical representations? Much time and effort was invested in the design of the representations by a large team and the representations can be considered to be typical for those found in textbooks in the educational sciences. Also, all representations took student task-demands into account. The structure of the six learning style themes were clearly and explicitly depicted or animated in the representations and specific posttest questions also focused on these features. This is important since recent studies (e.g., Schnotz & Bannert, 2003) have proven that non task-appropriate representations do not foster comprehension and mental model construction.

A second methodological point is that CTML-studies of Mayer and his colleagues is almost always of very short duration. Learning processes limited to 180 seconds are more the norm than the exception. In the present studies, larger chunks of learning content had to be processed by the students, during a longer period of time, so it is possible that the study tasks in the current study were more demanding than in Mayer's studies. Tabbers et al. (in press[a]) also mention this particular divergence between their studies and Mayer's as a potential source of inconsistency. In the context of a follow-up study, more attention could be paid to monitoring the study time as co-variable.

A critical issue is the fact individual differences were not taken into account. Since the research group was very homogeneous in terms of prior knowledge, it did not seem useful to take this into account. The intention was to make this an issue for future research. Mayer's seventh guideline (2001a) refers to the impact of prior knowledge and spatial abilities. Recent research by Cox (1999) reveals that "there are large variations between subjects in the types and modalities of visual representations that they use in their solutions" (Cox, 1999, p. 356). He concludes that representations might serve different cognitive functions for different subjects. In addition to prior knowledge other variables such as learning styles or spatial abilities can help explain the research results.

Time on task is an important factor in a lot of researches and analyses. This research had, as said in the part materials, no time limit; students could work as long as they wanted on their material. The variable time was not included in this research, but will be taken into account in future researches.

Implications for Instructional Design and Future Research

The central research hypothesis of this study questions the generic nature of the guidelines derived from CTML. The results suggest that instructional designers need more carefully consider the nature of the depictive representations they add to their learning materials. In the context of the present study, the focus was upon the educational sciences knowledge domain. This knowledge domain cannot be compared to the natural sciences where it is easier to build up depictive representations with high levels of repleteness. The results of the present study suggest that developers of learning materials pay explicit attention to *repleteness* as a central quality of the representations. Second, they could either design the representations in such a way that it would help learners understand the symbol system used, or they could ask students to develop representations themselves. Van der Pal and Eysinck (1999) suggest an additional approach, namely building up a specific formal language that learners have to master in order to build representations.

Considering the methodological remarks and the implications for instructional design, key characteristics of future research can be delineated. Future research should take into account extra co-variables related to individual differences between learners. A number of new research conditions could be included in the studies to contrast students that study learning materials enriched with representations and receiving or not receiving extra help, with or without prior introduction about / training in the iconic symbol system used or in the design of their own representations of the learning content. This last idea could be expanded with groups being supported with the new generations of CSCL-environments in which specific representation tools are available.

In other words, a second generation of CTML-research is needed that considers the unique affordances of representations in relation to their active processing by learners.

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Chapter 3[*]

The conditional nature of iconic symbol systems in the design and use of multimedia learning

Abstract

Although the Cognitive Theory of Multimedia Learning (CTML) is appealing to instructional designers, this theory is questioned in the present study. The mastery of the iconic symbol system is positioned as a central process in the discussion of the efficiency and efficacy of multimedia representations. In a 3x2 factorial research design, 286 participants (freshmen educational science) were randomly assigned to one of three experimental conditions in which they studied learning materials from two different knowledge domains: text only (T), text and visual representations (T+V) and visual representations enriched with audio (V+A). The results underpin to some degree the critical impact of the mastery of the iconic symbol system used to develop representations in multimedia learning materials. Also cognitive load is affected when iconic symbol systems are used that learners are less familiar with.

General research problem

Multimedia have become an omnipresent part of today's learning materials. Learning materials have changed under the influence of television, copy machine, computer, and so forth. Next to a textual elaboration, learning materials are enriched with a variety of static and/or dynamic visualisations, such as schemas, tables, graphs, charts, maps, diagrams, pictures, animations, video clips. The use of multimedia in learning materials can lead, according to Cognitive Theory of Multimedia Learning (CTML), to higher learning performance (see Mayer 2001a, 2001b, 2003, 2005). The theory states that the multimedia elaboration invokes in learners specific cognitive processes fostering schema development and schema integration. Although there is clear empirical evidence to ground the CTML-assumptions, there is a growing body of research that is not able to replicate these positive results.

The present study is part of the latter set of studies, but tries to extend the CTML by stressing the importance of the iconic symbol system used to develop graphical multimedia learning materials in a particular knowledge domain. The focus of the present study is on a particular type of multimedia elaborations: visual representations. These vary from very concrete and depictive to abstract and schematic, and either build on concrete images or very abstract iconic symbol signs. The iconic symbol signs have to be interpreted in a correct way by learners. This introduces the issue of the critical mastery of the iconic symbol system. It is

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our assumption that the impact of multimedia representations in learning materials is related to the correct interpretation by the learner of the iconic symbol system used in a specific representation. In view of a correct interpretation, iconic symbol systems have to be mastered.

The present study focuses on learners studying learning materials from knowledge domains they are either well or either not well acquainted with. These learning materials have been enriched with typical graphical representations. The difference in mastery of the iconic symbol system in both knowledge domains is expected to interact with the expected learning support from the multimedia representations as predicted by the CTML. After a discussion of the theoretical base about multimedia representations in general and the iconic symbol system in particular, we present the design and result of an empirical study to test research questions related to the central research problem.

Theoretical framework

The cognitive theory of multimedia learning

Multimedia representations are part of everyday life, including the context of education (Gilbert, 2005; Roth & Lee, 2004). The empirical evidence that underpins the educational potential of representations has influenced educators and instructional designers to integrate them in learning materials (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Mayer, 2001a, 2003, 2005; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schnotz, 2002; Schwan & Riempp, 2004). Many of these attempts are either based upon or inspired by the CTML which presents a clear theoretical framework to describe and explain the hypothetical positive impact of adding multimedia representations to texts.

The CTML is based on three assumptions, namely (1) the dual channel assumption (two channels indicating that learners have available two process information channels at the same time: a visual and a verbal channel (Baddeley, 1992, 1995 and Paivio, 1978, 1990, 1991); (2) the active processing assumption that states that learners are active information processors (Cyrs, 1997, Jonassen, 2000, Mayer, 2001a, 2003, 2005 and Wittrock, 1989) and (3) the limited capacity assumption that states that the capacity of working memory is limited (Chandler & Sweller, 1991; Sweller, 1988, 1989, 1994, 2005).

Building on these assumptions, Mayer (2001a, 2001b, 2003, 2005) presented seven guidelines for developing multimedia learning materials which are summarized in Table 1: (a) the *multimedia guideline*: learners benefit more from printed text enriched with visual representations than from printed text alone, (b) the *temporal contiguity guideline*: learners perform better when corresponding printed text and visual representations are presented simultaneously instead of successively, (c) the *spatial contiguity guideline*: learning is fostered when printed text and visual representations are presented close to one another on a page or on screen, (d) the *coherence guideline*: learning performance is higher when extraneous sounds, words, visual representations are excluded, (e) the *modality guideline*:

Table 1. Guidelines of CTML

Guideline	**Assumption/effect**	**Researches**
The multimedia guideline	Learners benefit more from printed text enriched with pictures than from printed text alone	Angeli & Valanides (2004) Goolkasian (2000) Guttormsen Schär & Kaiser (2006) Mayer (2003a, 2003b,2005) Mayer & Gallini (1990) Mayer & Sims (1994)
The temporal contiguity guideline	Learners perform better when corresponding printed text and pictures are presented simultaneously instead of successively	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The spatial contiguity guideline	Learning is fostered when printed text and pictures are presented close to one another on a page or on screen	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The coherence guideline	Learning performance is higher when extraneous sounds, words, pictures are excluded	Mayer (2003, 2005) Mayer & Moreno (2000) Seufert (2003)
The modality guideline	Learners learn more from animation enriched with audio (narration) than from animation enriched with printed text	Leahy, Chandler, & Sweller (2003) Mayer (2003a, 2003b, 2005) Mayer & Anderson (1991, 1992) Moreno & Mayer (1999) Tabbers, Martens, & Van Merriënboer (2004)
The redundancy guideline	Learners perform better when presented with animation and narration instead of animation and narration combined with printed text matching the narration	Mayer (2003a, 2003b, 2005) Mayer, Bove, Bryman, & Tapangco (1996)
The individual differences guideline	All guidelines have a stronger impact with low prior knowledge learners and learners with higher spatial abilities	Mayer (2003a, 2003b, 2005) Mayer, Sobko, & Mautone (2003) Moreno & Duràn (2004) Roth & Bowen (2003)

learners learn more from animation enriched with audio (narration) than from animation enriched with printed text, (f) the *redundancy guideline*: 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 guideline*: all guidelines have a stronger impact with low prior knowledge learners and learners with higher spatial abilities (see Mayer, 2001a, 2001b, 2003, 2005 for an overview). There is large body of empirical evidence that supports the efficacy of these guidelines (Mayer, 2001a, 2001b, 2003; Mayer & Anderson, 1991, 1992; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer & Gallini, 1990; Mayer & Moreno, 1998, 2000, 2003; Mayer & Sims, 1994).Building on the limited capacity assumption, also other researchers have pointed at the critical role of cognitive load when processing multimedia. For example, ineffective elements in the presentation format of learning materials, or poorly designed or poorly presented learning materials cause extraneous cognitive load. This type of cognitive load can be decreased by e.g., optimizing the representation format of the learning materials, resulting in higher learning performance (Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 1998; Mayer, Steinhoff, Bower, & Mars, 1995; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995; Sweller, Van Merriënboer, & Paas, 1998).

The conditional nature of the iconic symbol system

As stated earlier, not all empirical research has been able to replicate the positive CTML findings (Brünken, Plass, & Leutner, 2004; Cox, 1999; De Westelinck, Valcke, De Craene, & Kirschner, 2005; Dobson, 1999; Dutke & Rinck, 2006; Goolkasian, 2000; Guttormsen Schär & Kaiser, 2006; Guttormsen Schär & Zimmerman, 2006; Huk, 2006; Lowe, 2003; Moreno & Duran, 2004; Prangsma, in press; Scaife & Rogers, 1996; Schnotz & Bannert, 2003). Some of these authors refer to the nature of the knowledge domains to explain the differences in impact. All knowledge domains build on specific more or less elaborated iconic symbol systems. An iconic symbol system is a way to represent concepts, relations, and definitions in a certain knowledge domain. These representations support information processing. As a result it is necessary that learners understand the ‘language’ that has been used to develop the representations. As an example, we found for instance the following example (figure 1) in the knowledge domain of chemistry. Ethylene or ethane is represented in different ways: a textual, a formula, and a molecule-based representation. Each representation requires a different iconic symbol system. In learners, each representation requires the mastery of the specific iconic symbol system.

The studies of Mayer and his colleagues were mostly set up in the field of the hard sciences (i.e., biology, physiology, and mechanics) and the representations were mostly related to ‘How things work’. These knowledge domains are characterised by well-defined, widely used and unambiguous iconic symbol systems to represent specific content and can be considered as building bricks of the particular knowledge domain (Aldrich & Sheppard, 2000; Gilbert, 2005; Gobert, 2005; Kozma & Russel, 2005; Roth, Pozzer-Ardenghi, & Han, 2005; Stieff, Bateman, & Uttall, 2005).

$H_2C=CH_2$

Figure 1. Different iconic symbol systems are used to represent the system chemical component.

In the social sciences (e.g., psychology, education, …) or the humanities (e.g. history, literature,…), these iconic symbol systems are less explicitly developed, are sometimes rather ambiguous or are even not available at all. Mastery of a particular iconic symbol system can only be reached through sufficient experience and practice (Dori & Belcher, 2005; Gilbert, 2005; Gobert, 2005; Kozma & Russel, 2005; Roth, 2003; Stieff, Bateman, & Uttall, 2005). In the literature, a differentiation is made between types of iconic symbol signs. Mayer differentiates between *verbal* and *pictorial* iconic symbol signs. Other authors examine symbol systems along a continuum from *descriptive* (abstract) to *depictive* (concrete) iconic symbol signs (Lohse, Biolsi, Walker, & Reuter, 1994). Text, formulae or logical expressions can be seen as descriptive iconic symbol signs that build on clear conventions (Schnotz & Bannert, 2003; Schnotz, 2002).

In contrast, depictive representations such as pictures, graphics or schemes do not build on comparable conventions. Depictive iconic symbol signs mirror structural characteristics of the original or from reality; for instance, a drawing of an Egyptian pyramid (Goodman, 1976). Though designers of this type of visual representations expect that learners will interpret the meaning of the representation in a correct way, research evidence points out that this is not always the case. In relation to his, Prangsma (in press) refers for example to the wrong interpretation of depictive representations from Roman history by 12-14 year old learners. She also points at the need for an explicit learning process that centers on developing a clear understanding of the visual representations. Goolkasian (2000) proved in this context that unimodal presentations outperform multimodal presentations under certain circumstances. Learning material developers therefore have to be wary about their expectations that learning materials building on multiple representations will foster higher learning performance. Also Guttormsen Schär and Kaiser (2006) showed that presenting different representations, also building on different iconic symbol systems, might result in different performance levels.

As a consequence, learners confronted with new or unknown iconic symbol systems might experience difficulties and/or need more time to process the representations in view of developing mental models. They are also expected to experience higher cognitive load. This could point to a mismatch between the learner's prior knowledge of the iconic symbol system used and the multimedia elaboration of the learning materials (De Westelinck, Valcke, De Craene, & Kirschner, 2005; Dobson, 1995, 1999; Goodman, 1976; Lewalter, 2003; Lowe, 2003; Roth, Pozzer-Ardenghi, & Han, 2005; Stenning, 1999; Stern, Aprea, & Ebner, 2003). The mastery level of iconic symbol system is therefore a precondition that instructional designers have to take into consideration when developing new learning materials.

In the literature, authors refer to a five-step learning path (table 2) to develop the conditional prior knowledge needed to interpret correctly iconic symbol systems and reach the mastery level of iconic symbol system (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005; Roth, 2003; Roth, Pozzer-Ardenghi, & Han, 2005; Wileman, 1993). At a basic level, the learner interprets the symbols as an iconic depiction which evolves along the next three more stages to a final stage where reflective use of the iconic symbols signs has become possible. The fifth level is considered as the mastery level, the end goal for scientist or student-scientists (Dori & Belcher, 2005; Kozma & Russel, 2005).

Table 2. Competence levels in the mastery of an iconic symbol system

Level 1	Iconic symbol signs as an isomorphic, iconic depiction.
Level 2	Early symbolic skills.
	The person is familiar with symbolic sign system but they use it without regards to syntax and semantics.
Level 3	Syntactic use of iconic symbol signs.
Level 4	Semantic use of iconic symbol signs.
Level 5	Reflective, rhetorical use of iconic symbol signs.

Roth (2003), Roth, Pozzer-Ardenghi and Han (2003) and Gilbert (2005) define the interpretation of iconic symbol signs as a semiotic activity during which three different elements interrelate: the sign, the referent and the interpretant. *Signs* are the material traces (i.e. pictures, graphs, …) that refer the reader to something others than themselves. *Interpretants* are commentaries on the sign, definitions of the sign in its relation to the *referent* object. Semiotics is the process during which interpretants are produced. The relation between signs and referents is arbitrary and the reading of these signs implies two processes: structuring and grounding. Figure 2 shows a representation of these processes. During the structuring process, the individual has to structure the visual field to construct the sign itself and to develop an interpretation. The grounding process entails that the sign plays a part in a dialectic process in sign-to-referent and referent-to-sign movements that mutually stabilize each other and also help to establish a corresponding referential ground for the sign (Gilbert, 2005; Roth, Pozzer-Ardenghi, & Han, 2005).

In the context of the CTML, we expect extraneous cognitive load to be lower due to the presentation of visual representations. The discussion above introduces a prior condition, and as such an additional CTML-guideline. Extraneous cognitive load will only be reduced when the learner masters the specific iconic symbol system used to develop the multimedia representation. The emphasis should therefore not only be on the multimedia format - as stated by CTML - but also on the mastery level of the iconic symbol system. If a learner does not sufficiently master the iconic symbol system in a new or unfamiliar knowledge domain, the visual representations might rather invoke a higher cognitive load, thus leading to poorer learning.

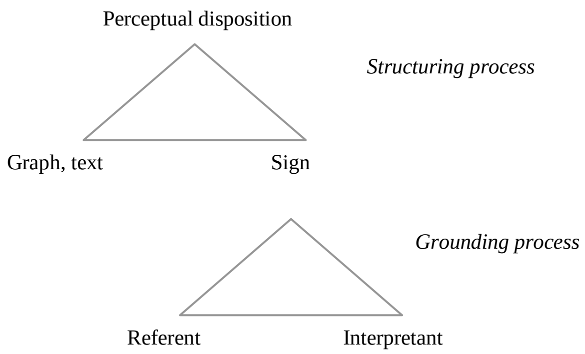


Figure 2. Grounding and structuring process of reading.

The former introduces the key research question of the study presented in this article by centering on the conditional nature of the mastery of the iconic symbol system that was used to develop multimedia representations.

Empirical study

General Research Question and Hypotheses

The central research question of this study is whether the level of acquaintance with the iconic symbol system - at the base of visual representations in learning materials – is an influencing factor on learning performance? Building on the theoretical base, the following hypotheses are put forward:

- Educational sciences students, studying multimedia learning materials in their knowledge domain, will attain higher knowledge and application test results and report lower levels of cognitive load as compared to studying multimedia learning materials from the field of the natural sciences, a knowledge domain they are less acquainted with.
- Learning performance and reported cognitive load will depend on the nature of the multimedia elaborations of learning materials (i.e. text only, text with visual representations and visual representations with audio).

Participants

Research participants were enrolled as freshmen in the Pedagogical Sciences programme of the faculty of Psychology and Educational sciences at Ghent University (Belgium). The entire population of freshmen participated in the study (N= 286). Participation was a formal part of the course ‘Instructional Sciences’ and planned as an advance organizer to a subsequent discussion about CTML. Informed consent was obtained from all participants prior to the experiment.

Prior to the admission to the university, almost 95% of the participants studied General Secondary Education. In the Flemish context, General Secondary Education gives access to higher education, and students can choose between a major in the humanities, social sciences or hard sciences. The majority of the students in this study took a major in humanities and social sciences; a minority studied a major in hard sciences.

At the time of the study, the educational science students were already enrolled for eight weeks in the educational sciences program. They can therefore be considered to be sufficiently acquainted with learning materials from this particular knowledge domain.

Research Design

A pretest-posttest 3x2 factoral experimental research design was adopted.

The pretest was administered to determine the prior knowledge level of participants in the particular knowledge domain. It was expected that the participants had low or non-existing prior knowledge of the content presented in the learning materials. Posttests were presented after each specific subset of learning materials. Posttests consisted of both knowledge and application questions.

The 3x2 factorial design was defined by the choice of two knowledge domains and three multimedia elaborations. To investigate whether acquaintance with the iconic symbol system influences performance of participants, two different knowledge domains were studied: natural sciences and educational sciences. Since educational sciences students were involved in the study, these students were considered to be already sufficiently acquainted with domain-specific knowledge representations. In both knowledge domains, learning materials were developed based on three different multimedia elaborations: text only (T), text and visual representations (T+V) and visual representations and audio (V+A). In the condition text only (T), participants receive learning materials consisting of text only. Participants in the V+T condition study learning materials consisting of text enriched with visual representations. Each part of text was accompanied by a graphical element representing the information stated in the text. These visual elements were developed according to the guidelines formulated by the CTML. In the V+A condition, audio was added to visual representations. In this condition, the original printed text was replaced by an audio track. Learning materials - in each condition and both knowledge domains - consisted of three subsets.

The random assignment of participants to the experimental conditions was marred by a number of organizational problems. This resulted in a larger proportion of participants in the V+A condition studying learning from the natural sciences (N 124 versus N 164). The research was set up as a cross-sectional study; performance of groups of participants assigned to one of the six research conditions are compared.

Learning Materials

In each of the six research conditions, learners were presented with three subsequent sets of learning materials. Since we compare the performance of participants studying learning materials from two different knowledge domains, outcome differences might be biased due to differences in the complexity of the learning materials. This was controlled for by studying the complexity of the learning content. Complexity of content was measured by looking at the number of interrelated concepts presented in the learning materials of each individual subset of learning materials. An overview of the level of complexity is given in table 3. The first and the third set or learning materials can be considered as being equally complex in both knowledge domains. In the second set of learning materials, a difference in complexity is perceived due tot the larger number of interrelated concepts in the educational sciences knowledge domain.

Table 3. Level of complexity

	Educational sciences		
	Set 1	Set 2	Set 3
N	124	124	124
Level of complexity	1.25	3.5	.90

	Natural sciences		
	Set 1	Set 2	Set 3
N	162	162	162
Level of complexity	1.2	2.8	.80

A second issues is related to the quality of the multimedia representations. Both the textual (audio or printed) and the visual representations adopted in the elaboration of the learning materials from each knowledge domain, are largely comparable to the approach adopted in school books, text books and commercially available learning materials.

In addition, to guarantee the optimal design of the multimedia elements in the learning materials, Mayer's design recommendations were strictly taken into account (2001a, p. 191-193). Table 4 presents the starting screen shots from the six sets of learning materials. In the domain of educational sciences, the first set focused on 'human memory', set two on 'the information processing model' and set three on 'metacognition'. In the natural sciences set one was about the 'water cycle', set two about 'storms' and set three about 'thunder and lightening'.

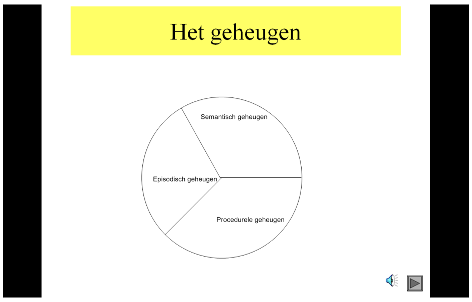
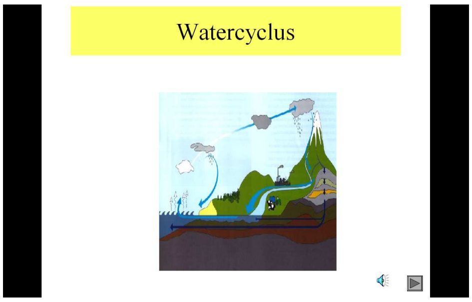
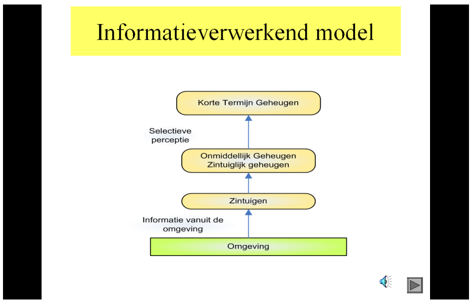
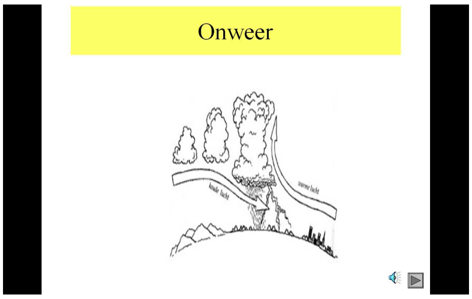
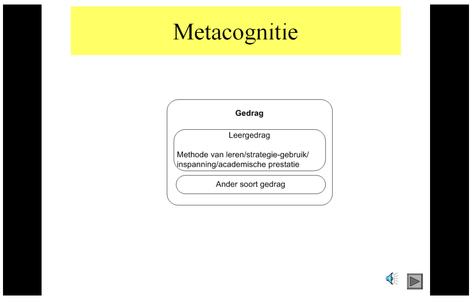
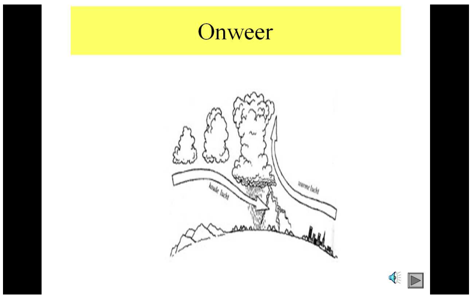
Specific attention was given to the design of the pretest and a posttest presented in relation to each set of learning materials. These tests consisted of knowledge and application questions. Knowledge questions focused on remembering elements about a topic (e.g., Give the control processes of the information processing model?). Application questions focused on problem solving and a deeper understanding of the learning content (e.g., Why can you feel thunder?).

Procedure

The starting point of this research was an overall pretest, to determine the prior knowledge level of the individual research participants. After administration of this paper and pencil test, the participants were invited to study the learning materials via a computer. After studying one of the three subsets of the learning materials, a paper and pencil posttest was presented. In addition, after studying the first and the second set of learning materials, participants were asked to report the experienced cognitive load when studying these materials. In the literature, measurement of cognitive load is mainly based on the learners' subjective reporting of their perceived mental effort. This results in a subjective cognitive load scale (Paas, Renkl, & Sweller, 1994), requiring the students to indicate the amount of effort they experienced on a scale varying from 0 to 9. Reported use of this type of scale results in high Cronbach's α reliability scores of .90 to .82 (Paas, 1992, Paas et al., 1994).

The answers to the knowledge and application questions were scored with the help of a correction and scoring key. Test scores were standardized. Two trained, independent scorers judged the answers to the open questions. Inter-rater reliability was calculated to control the quality of the scoring of 25% of the test items (Rourke, Anderson, Garrison & Archer, 2001). A person agreement of 83.33% reflects a high reliability. In the results section, post test results in relation to the three different sets of learning materials are reported for each research condition.

Table 4. Screenshots of every set in each knowledge domain

	Educational sciences	Natural sciences
Set 1		
Set 2		
Set 3		

Results

In this part, first the descriptive results are discussed, followed by results in relation to both hypotheses.

Descriptive results

Table 5 and Figure 3 present the descriptive results after studying all sets of learning materials in both knowledge domains and in relation to the different multimedia elaborations. Analysis of the pretest results revealed that prior knowledge, in both knowledge domains, was low and did not differ significantly between knowledge domains. As such, the pretest scores were not taken into account during subsequent statistical analyses.

The means in table 5 show that posttest results in the field of the educational sciences are in most cases higher than in the natural sciences. With respect to the multimedia elaboration of learning materials, different posttest scores were noted. The T+V condition leads to the highest posttest results. This is not the case for the V+A condition. Cognitive load seems to be the highest in the V+A condition.

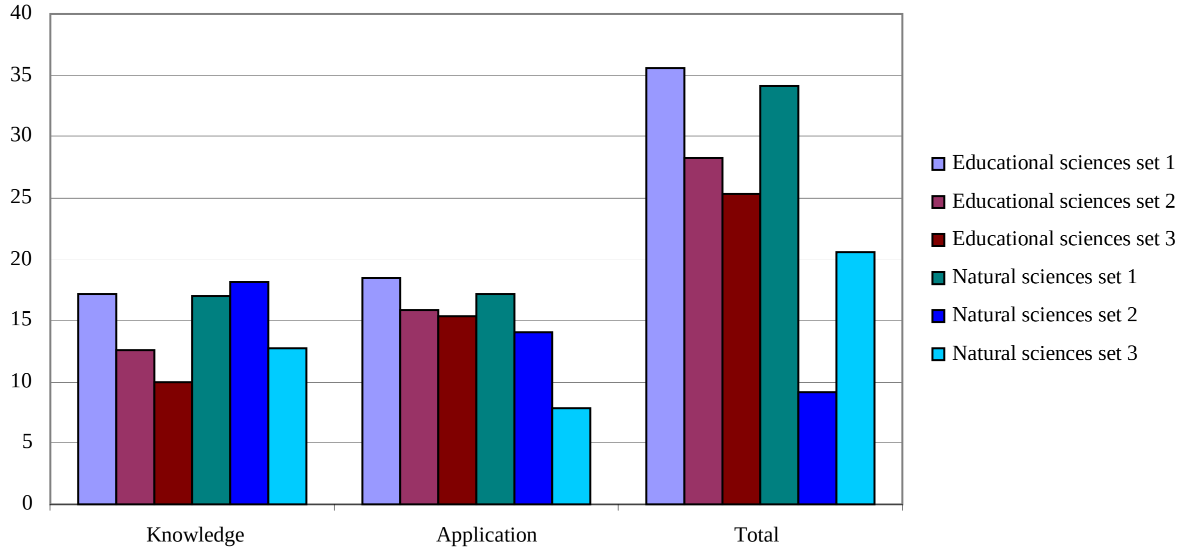


Figure 3. Graphical representation of the knowledge, application and total scores after studying learning materials from two different knowledge domains.

Hypothesis 1

The descriptive results point at a potential interaction effect between posttest scores and the knowledge domain. We expect that educational sciences students report significantly higher scores after studying learning materials from the educational sciences since they are more familiar with the iconic symbol system used to develop the multimedia representations. Lower posttest scores would be attained after studying learning materials from the natural sciences since they are less acquainted with the specific iconic symbol system applied in these learning materials.

Table 6 reports the t-test results in view of testing the first hypothesis. The t-tests were applied in relation to the three subsets of both knowledge domains and separately for both the knowledge questions, the application questions and the total posttest scores. Significant differences in favour of the educational sciences are observed in the first set of the learning material for the application posttest scores (t = -2.86, df = 281,07, p < .05; d = .33) and in the third set on the application posttest score and the total posttest score (t =-8.52, df = 240,27, p < .05; d = 1.03; t = -4.31, df = 240.68, p < .05; d = 0.52). This indicates a higher mastery level by educational sciences students after studying these learning materials. In contrast to our expectations, the second set of learning materials resulted in significantly higher posttest results in the field of the natural sciences for both the knowledge and total posttest scores (t = 8.60, df = 198.18, p < .05; d = -1.05) and the total posttest score (t = 3.12, df = 230,78, p < .05; d = -0.38). This can be related to the higher complexity level or the learning materials in the second subset of educational sciences learning materials.

The analysis results in relation to the reported cognitive load are consistent. Studying learning materials from a less familiar knowledge domain (natural sciences) results in higher cognitive load scores. This suggests the interplay of the lower mastery of the iconic symbol system. But the analysis results point out that the differences are not statistically significant.

Hypothesis 2

Hypothesis two is in line with typical CTML-research that studies the differential impact of alternative multimedia presentations. But considering the expected impact of the mastery of the iconic symbol system, it is expected that it will be easier to find support for the CTML-guidelines in a knowledge domain the students are acquainted with.

Three different multimedia representations were applied when elaborating the learning materials in both knowledge domains: text only (T), text and visual representations (T+V) and visual representations and audio (V+A). Analysis of variance helps to compare the differential impact of the different multimedia representations. Table 7 summarizes the analysis results and table 8 presents the posthoc results in case observed differences are significant.

In the knowledge domain of the educational sciences, significant differences were observed. In summary, studying the T+V version results in higher learning performance as compared to studying the text only version or studying the V+A version. Studying the different multimedia versions of the learning materials in set 1 resulted in significant differences in knowledge posttest scores (F(2,121) = 4.25; p < .05), application posttest scores (F(2,121) = 5.62; p < .05), and total posttest scores (F(2,121) = 5.10; p < .05). The posthoc tests make it clear that the students in the condition V+A score in general lower than the others. Studying the learning materials in set 2 resulted in comparable findings, since significant differences were found in both the knowledge posttest scores (F(2,120) = 49.13; p < .05) and the total posttest scores (F(2,120) = 49.13; p < .05 for knowledge test (F(2,120) =

Table 5. Mean scores and standard deviation for knowledge, application and total posttest scores for each set of learning materials in both knowledge domains

		Educational sciences (n=124)								Natural sciences (n=162)							
		Visual Representation + Audio (n=43)		Text + Visual Representation (n=45)		Text only (n=36)		Total		Visual Representation + Audio (n=84)		Text + Visual Representation (n=36)		Text only (n=42)		Total	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Know	15.81	6.63	16.67	5.22	19.17	2.81	17.10	5.38	17.34	3.83	18.24	3.52	15.16	3.62	16.98	3.86
Set	Applic	17.36	4.32	19.51	1.41	18.58	2.50	18.49	3.11	17.42	4.37	18.61	2.91	15.56	5.44	17.20	4.52
1	Tot	33.18	8.66	36.17	5.47	37.75	4.39	35.59	6.73	34.76	6.26	36.85	5.46	30.71	7.56	34.18	6.79
	Know	7.11	5.85	16.96	3.07	13.56*	4.90	12.55	6.31	17.98	4.60	19.44	2.32	15.50	4.17	18.18	4.25
Set	Applic	14.42	9.08	16.00	8.09	17.22	7.02	15.81	8.18	13.71	7.56	14.22	8.03	14.38	7.07	14.00	7.50
2	Tot	21.53	10.98	32.96	9.02	30.70*	10.16	28.32	11.20	31.69	9.89	33.67	7.95	31.88	8.35	32.18	9.09
	Know	8.33	4.62	11.29	4.12	10.33	5.09	9.98	4.73	12.86	4.11	14.07	4.72	11.27	3.45	12.72	4.19
Set	Applic	13.18	9.14	17.04	6.44	15.74	7.15	15.32	7.79	8.49	7.12	8.15	6.97	6.51	4.99	7.90	6.61
3	Tot	21.50	11.50	28.33	7.84	26.07	8.10	25.31	9.71	21.35	9.13	22.22	7.13	17.78	6.69	20.62	8.27
	Cognitive load 1	4.76**	2.25	3.67	1.85	3.94	2.07	4.11	2.09	4.90	2.36	4.67	1.93	4.05	2.12	4.63	2.22
	Cognitive load 2	6.27***	1.97	5.93	1.85	5.94	1.84	6.04	6.04	6.43*****	1.89	5.81	1.62	5.73**	1.99	6.11	1.88
	Cognitive load	5.54****	5.54	4.80	1.54	4.94	1.54	5.07	5.07	5.67*****	1.95	5.24	1.42	4.90**	1.79	5.38	1.82

Table 6. Posthoc results on knowledge, application and total score for each set

		T	Df	*p*	*d*
Set 1	Knowledge	-.21	213.69	.83	
(n=286)	Application	-2.86	281.07	.00	.33**
	Total	-1.75	284	.08	
Set 2	Knowledge*	8.60	198.18	.00	-1.05**
(n=286)	Application	-1.94	284	.05	
	Total*	3.12	230.78	.00	-.38**
Set 3	Knowledge	5.09	247.17	.00	-.61**
(n=286)	Application	-8.52	240.27	.00	1.03**
	Total	-4.31	240.68	.00	.52**
	Cognitive load 1 ***	1.98	282	.05	
	Cognitive load 2****)	.31	276	.76	
	Cognitive load *****	1.43	275	.15	

N*=285.* *N*=284.**** *N*=278.******N=277*. **significant at 5% level

Table 7. Overview of anova results

	Educational sciences (n=124)									Natural sciences (n=162)								
	Set 1			Set 2			Set 3			Set 1			Set 2			Set 3		
	df	*F*	*P*	*df*	*F*	*P*	*df*	*F*	*P*	*df*	*F*	*p*	*df*	*F*	*p*	*df*	*F*	*p*
Know	2,121	4.25	.02*	2,120	49.13	.00**	2,121	4.73	.01*	2,159	7.54	.00**	2,159	2.41	.09	2,159	4.64	.01*
Applic	2,121	5.62	.01*	2,121	1.18	.31	2,121	2.85	.06	2,159	4.86	.01*	2,159	.13	.88	2,159	1.30	.28
Total	2,121	5.10	.01*	2,120	15.57	.00**	2,121	15.57	.00**	2,159	9.46	.00**	2,159	.62	.54	2,159	3.60	.03*

	df	*F*	*P*	*Df*	*F*	*p*
Cognitive load 1	2,119	3.20	.05	2,159	2.12	.12
Cognitive load 2	2,115	.40	.68	2,157	2.59	.08
Cognitive load	2,114	2.35	.10	2,157	2.61	.08

*significant at 5% level
**significant at 1% level

15.57; $p < .05$). Posthoc analyses make it clear that the condition V+A leads to lower learning performance. Studying the learning materials in set 3 revealed significant results in both the knowledge posttest scores ($F(2,121) = 4.73$; $p < .05$), and total posttest scores ($F(2,121) = 15.57$; $p < .05$). Again posthoc results make it clear that the multimedia elaboration with audio (V+A) leads consistently to lower learning performance.

Table 8. Overview of significant results and effect-sizes

	Educational sciences		
Set 1	Knowledge	T > V+A	F (2,121) = 4.25, *p* =.01, *d* = .66
	Application	T+V > V+A	F (1,121) = 5.62, *p* =.01, *d* = .67
	Total	T > V+A	F (2,121) = 5.10, *p* =.01, *d* = .66
Set 2	Knowledge	T > V+A	F (2,120) = 49.13, *p* = .00, *d* = .26
		T+V > V+A	F (2,120) = 49.13, *p* = .00, *d* = 2.11
		T+V > T	F (2,120) = 49.13, *p* = .00, *d* = .14
	Total	T > V+A	F (2,120) = 15.57, *p* = .00, *d* = .87
		T+V > V+A	F (2,120) = 15.57, *p* = .00, *d* = 1.14
		T +V > T	F (2,120) = 15.57, *p* = .00, *d* = .24
Set 3	Knowledge	T+V > V+A	F (2,121) = 4.73, *p* = .01, *d* = .68
	Total	T+V > V+A	F (2,121) = 15.57, *p* = .00, *d* = .69
	Natural sciences		
Set 1	Knowledge	T+V > V+A	F (2,159) = 7.54, *p* = .00, *d* = .24
		T +V > T	F (2,159) = 7.54, *p* = .00, *d* = .86
	Application	T+V > V+A	F (2,159) = 4.86, *p* = .01, *d* = .32
		T +V > T	F (2,159) = 4.86, *p* = .01, *d* = .70
	Total	T+V > V+A	F (2,159) = 9.46, *p* = .00, *d* = .36
		T +V > T	F (2,159) = 9.46, *p* = .00, *d* = .93
Set 3	Knowledge	T +V > T	F (2,159) = 4.64, *p* = .01, *d* = .83
	Total	T +V > T	F (2,159) = 3.60, *p* = .03, *d* = .64

In the natural sciences, comparable results are found: studying the T+V version results in higher learning performance as compared to studying the text only version or studying the V+A version. Significant differences were found in posttest scores for set 1 and set 3 of the learning materials. In set 1, there were differences in the knowledge posttest scores ($F(2,159) = 7.54$; $p < .05$), application posttest scores ($F(2,159) = 4.86$; $p < .05$) and the total posttest scores ($F(2,159) = 9.46$; $p < .05$). Posthoc tests point out that participants studying the learning materials in the T+V condition scored significantly higher as compared to participants in the other conditions. Set 3 revealed significant results for the knowledge posttest scores ($F(2,159) = 4.64$; $p < .05$), and total posttest scores ($F(2,159) = 3.60$; $p < .05$). Also in this condition the multimedia elaboration based on T+V lead to higher performance of the participants.

Although a difference in reported cognitive load was observed in the six conditions in both knowledge domains, differences were not significant. The following trend was observed in both knowledge domains: participants in the V+A condition reported a higher cognitive load as compared to participants in the T+V condition. Participants in the T+V condition reported higher experienced cognitive load as compared to participants in the Text only condition.

Discussion

The aim of this research was to answer the question whether the mastery of an iconic symbol system that is at the base of a visual representations, affects the impact of multimedia elaborations as predicted by the CTML-assumptions. In other words, the impact of the multimedia elaboration of learning materials was hypothesized to be dependent on the level of acquaintance of learners with the iconic symbol system that was used to develop a multimedia representation.

To test the first hypothesis about the differential impact of familiarity with an iconic symbol system in different knowledge domains, participants were assigned at random to different research conditions to study learning materials of comparable complexity but from different knowledge domains. The descriptive results and the significant analysis results point at a potential differential impact. Participants studying learning materials from the more familiar educational sciences knowledge domain, obtained significantly higher posttest scores in most sets of learning materials and in most alternative multimedia elaborations of the materials. These results give support to our first hypothesis and are in line with findings of some other studies. Bowen and Roth (2003), Roth and Bowen (2003) and Roth, Bowen and Masciotra (2002) found that student have difficulties in interpreting graphs and consequently processing new knowledge. But, our analysis results are not consistent. Some posttest scores in the domain of the educational sciences are not as high as expected. But, in our opinion this can be explained by the complexity level of the learning materials in the second set of learning materials. The learning materials from the knowledge domain of the educational sciences were more complex (a higher number of interrelated concepts) as compared to the learning materials in the natural sciences in subset 2 (see again table 3). This explains the contradictory results when comparing posttest results after studying set 1 and 3 with the posttest results after studying the second set of materials. An additional explanation for the less consistent results could be related to the fact that the participants in the present study were still novices when it comes to studying the educational sciences. After eight weeks of being involved in the university programme, it is possible they are still not very thoroughly acquainted with the typical iconic symbol system used in this knowledge domain. Some authors insist that it takes time and experience before a sufficient mastery level of an iconic symbol system can be expected (Dori & Belcher, 2005; Gilbert, 2005). The large standard deviations in mean posttest scores confirm our assumption that there is a large heterogeneity in mastery level of the iconic symbol system of the educational sciences (see Table 5). In addition, the multimedia representations in the field of the educational sciences could have been more ambiguous due to their descriptive nature as compared to the depictive nature of the representations in the field of the natural sciences.

An analysis of the cognitive load as reported by the participants, points at a clear trend. The reported cognitive load is higher when studying learning materials from the natural sciences although differences are not significant. In summary, the first hypotheses can only be partially accepted since, yet, we do not observe consistently significantly higher performance when studying materials from the educational sciences.

The second hypothesis focused on the differential impact of alternative multimedia representations on learning performance and cognitive load in both knowledge domains. In a consistent way, we find that Mayers' multimedia guideline is reconfirmed (Text+Visual representation > Text only). But, when analysing the significant differences in the posttest results and especially the results of the post hoc analyses (table 8), we can observe a more consistent pattern in the significant differences when participants study materials of the knowledge domain they are better acquainted with (educational sciences). Support for these results can be found in a number of studies. Cox (1999), for example, states that the impact of graphical versus textual representations might be affected by the degree to which learners understand the semantics of the iconic symbol system. This is also consistent with the findings of Lowe (2003), namely that subjects extract information easier from signs that reflect clear visual-spatial characteristics, such as structural coherence and distinctive appearance (e.g., closely related to reality). Support is also found in Schnotz and Bannert (2003) who conclude that adding pictures to text is not generally beneficial, and that the representations can even have negative effects on learning because they may interfere with the construction of mental models. In the context of the present study, we assume that the latter is especially the case in the field of the natural sciences as participants are less acquainted with it. Seufert (2003), in relation to the previous, stated that the benefits of multimedia representations are expected to be more efficient when support is given considering the level of prior knowledge participants posses.

The present study also puts forward expectations that differ from the CTML-theory; and this in particular to the potential impact of adding audio (modality guideline) to learning materials in a domain the participants are less acquainted with. If audio is added in the latter case, cognitive load will increase and so more difficulties in the development and integration of mental models are expected to be experienced. The analyses reveal that in neither knowledge domain did the modality guideline have a beneficial impact.

In both knowledge domains, we perceive that the Text only or the Text + Visual Representations version of the learning materials leads to higher performance as compared to materials developed in line with the modality guideline (Visual representations + Audio). Significant differences are more pronounced in the field of the educational sciences. Our expectation has been confirmed when participants study learning materials from the natural sciences. Adding audio does not result in a significantly higher learning performance. In a number of cases (see set 1), applying the modality guideline even leads to significantly lower learning performance. These results are in line with the findings in a growing number of studies (see e.g., Dutke & Rinck, 2006; Goolkansian, 2000; Guttormsen Schär & Zimmerman, 2006; Prangsma, in press).

The fact that the claims of the modality guideline are not confirmed when studying materials from the educational sciences is a strange finding. This can be explained in a number of ways. First, as pointed out earlier, the expertise level of the participants in this particular knowledge domain might still have been too restricted to master the underlying iconic symbol system. Second, the nature of the representations to support the processing of complex information is different: descriptive instead of depictive. Other authors, such as Leahy, Chandler and Sweller (2003) concluded earlier that the effectiveness might depend on how and when audio elaborations are being used. In this perspective the role of social cues in audio elaborations was also questioned by Mayer, Sobko and Mautone (2003).

Although we observe the expected trend regarding the differences in cognitive load, none of the observed differences was significant. These result help to conclude that applying the modality guideline does yet not result in lower cognitive load as hypothesized by the initial CTML.

Limitations and recommendations

In the present study, hypotheses were tested about the potential differential impact of the mastery of an iconic symbol system when discussing the role of multimedia representations. The results of the present study present some evidence to discuss pre-conditions in the context of the CTML-theory: the mastery of the iconic symbol system that is at the base of multimedia elaborations. But, the research approach adopted in the present study can be criticized from a number of perspectives. First, the research sample consisted only of freshman in the educational sciences. It can be questioned whether the findings can be generalized to students studying other programs, knowledge domains or at other educational levels. Second, a more elaborated test of the hypotheses about the critical mastery of the underlying iconic symbol system, could be realized when involving students from different programs (e.g., social science students versus engineering study students) and presenting these students with multimedia learning materials from each others knowledge domain. In this future study, the latter approach should replace the cross-sectional characteristic of the present study. Third, research involving larger samples are needed to check whether the results of the present study can be replicated. Fourth, the question can be raised whether specific student variables, such as learning styles, study approach, prior educational background and pacing also interact with variables and/or processes studied in this research. Since our research sample was rather homogeneous in terms of prior knowledge, we consider that the role of prior knowledge is of less significance. Nevertheless, future research should consider Mayer's (2001a) seventh guideline about individual differences in for example prior knowledge or other student characteristics. Research of for example Cox reveals that "there are large variations between subjects in the types and modalities of external graphical representations that they use in their solutions" (Cox, 1999, p. 356). She also concludes that iconic symbol systems might serve different cognitive functions for different subjects.

When studying the differential impact of individual differences, the adoption of other statistical analysis techniques should be considered, such as multilevel analysis and structural equation modeling. This would allow to cater for the nested nature of students, in groups, and in knowledge domains. Path modeling could help to study in more detail the impact of mediating variables. Fifth, questions can be raised about the quality of the multimedia representations. Do the results rather reflect the influence of less effective elaboration of for example visual representations? This is important since recent studies (see e.g., Schnotz & Bannert, 2003) give support to the assumption that non task-appropriate representations do not foster comprehension and mental model construction. As explained, much time and effort was invested in the design of the representations by a team of different designers. The representations were moreover typical for the approach found in textbooks in the field of educational sciences or natural sciences. Sixth, questions about the selection and complexity level of the specific learning content can be put forward. This was an issue of particular importance when designing the present study. The researchers build on about five years of experience in developing learning materials for freshman courses. In addition, the complexity level of the learning materials was scrutinized in detail. Future research should consider complexity levels in a more profund way. Replication studies are needed to assure that this variable does not confound the results. In addition, specific research concerning 'complexity levels' should be performed. A seventh question focuses on the duration of the studies. The original CTML-studies of Mayer and his colleagues were limited in time. In the present studies, larger chunks of learning materials were studied during a longer period of time. It is possible that more demanding study tasks result in divergent research results as compared to Mayer's original studies. Also Tabbers, Martens and Van Merriënboer (2004) mention this particular divergence between their studies and these by Mayer as a potential source of ambiguous research results. Another remark is related to the timing of the posttest, administered immediately after studying the learning materials. In future research, a delayed impact of the alternative multimedia presentations could be studied. In a recent study, researcher found that posttest results differed when focusing on immediate posttest results and long-term posttest scores (Atkinson, Clark, Harrison, Koenig, & Ramirez, 2007). This research determined the prior knowledge of the participants concerning the content of the learning materials. It would have been ideal if also the prior knowledge (level of mastery) concerning the use of the iconic symbol system in a certain knowledge domain was determined. Future research should include this in the experimental design. A last, but remarkable fact is related to the condition where audio is integrated. A very interesting fact is that, in contrast to what was expected, this condition leads to lower learning performance and higher levels of cognitive load. Even though the dual channel assumption is respected and both ears and eyes are used, the participants do not attain higher performance. Several possible explanations can be presented. Maybe the words in the audio part were not pronounced very clearly. This can be related to the personal preferences of participants regarding voices. It is also possible that the background noises, which are inevitable in a room with about 40 research participants, marred the understanding of the audio. In addition, these students were not used to study this kind of learning materials. Studying via audio and visual representations only was new to the participants; this might have affected their performance.

Building on our results and the limitations discussed above, directions for future research can be defined. Considering the familiarity with an iconic symbol system, future studies could centre on explicit instructional interventions to develop the mastery of an iconic symbol system. In addition, a more active role of students could be studied in the context of understanding and interpreting multimedia representations. This could be done by asking students to develop their own multimedia representations and/or building on personal available iconic symbol systems. The latter idea could be expanded with a study that centers on the impact of student collaboration in working with pre-defined or self-developed knowledge representations.

Conclusions

Though a large body of empirical evidence is available that grounds the guidelines derived from the cognitive theory of multimedia learning, not all research is able to replicate the positive findings. These studies did inspire the present study to centre on the conditional mastery of the iconic symbol system underlying a multimedia representation. Some evidence could be presented that points at the mediating impact of the mastery of the iconic symbol system when adopting the CTML-principles as design guidelines for multimedia learning materials. The results are inspiring for future research that focuses on the nature and the extent of mastery of iconic symbol systems. In addition, the results suggest to set up future research about instructional interventions fostering familiarity with a particular iconic symbol sign, or to promote the development of a personal iconic symbol system. These studies could also involve groups of students developing and/or sharing iconic symbol systems to be used when studying complex learning materials.

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Chapter 4[*]

Extending the Cognitive Theory of Multimedia Learning with the activation guideline

Abstract

In an experimental design, 219 participants were randomly assigned to one of four experimental conditions based on the study of multimedia learning materials: text only (T), text and visual representations (T+V), text and pre-worked examples of visual representations (T+PW) and text and development of the visual representations by the participants (T+D). The results reveal that participants expected to be more actively involved in elaborating or developing visual representations attain higher learning performance scores and report lower levels of perceived cognitive load. The findings about this 'activation guideline' underpin assumptions about the critical impact of the mastery of the iconic symbol system used to develop representations in multimedia learning materials. Since the results are not consistent for each set of learning materials, limitations of the study are discussed and directions for future research are put forward.

Introduction

A key characteristic of present-day learning materials is their multimedia-elaboration. Learning materials not only contain text but also audio, and/or other graphical representations such as static and/or dynamic visualizations. Examples of the latter are schemas, tables, graphs, charts, maps, diagrams, pictures, animations, video clips and so forth. In the present study we focus on the potential effects of enriching learning materials with graphical representations, also referred to as visual representations or graphical models (Gemino & Wand, 2005).

Many authors argue that the multimedia elaboration of learning materials has the potential to foster learning performance (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schwan & Riempp, 2004). A clear understanding of the mechanisms that help to explain the positive impact of multimedia is crucial to direct future design and development activities (Butcher, 2006). In this context, Mayer conceptualized his Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2001a, 2001b, 2003) presenting at the same time a list of principles that can be

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applied as guidelines to direct the design of multimedia learning materials. Although there is clear empirical evidence supporting the assumptions of the CTML (Mayer, 2005), a growing body of research indicates that the findings don’t seem to be replicated in a consistent way (Brünken, Plass & Leutner, 2004; Cox, 1999; Dobson, 1999; Dutke & Rinck, 2006; Goolkasian, 2000; Guttormsen Schär & Kaiser, 2006; Guttormsen Schär & Zimmerman, 2006; Huk, 2006; Lowe, 2003; Moreno & Durán, 2004; Postigo & Pozo, 2004; Prangsma, in press; Scaife & Rogers, 1996; Schnotz & Bannert, 2003). This resulted in a series of studies, set up by the present authors, to study the validity of the, CTML-guidelines in the knowledge domain of the social sciences. (De Westelinck, Valcke, De Craene, & Kirschner, 2005; De Westelinck & Valcke, 2005). In this particular knowledge domain, application of the CTML-guidelines proved to be less successful. Discussion of these results suggested that a way to explain the conflicting empirical results, is by focusing on the limited mastery of the iconic symbol system that is at the base of visual representations in a particular knowledge domain, also called ‘symbolic literacy’ (Eskritt & Lee, 2007). As synonyms for ‘iconic symbol systems’, authors use concepts such as ‘notations’ or ‘permanent external symbols’. From this perspective, the iconic symbol system is considered as a particular knowledge subset of a knowledge domain (De Westelinck, Valcke, & Kirschner, submitted). The present article builds on these earlier studies and puts forward the activation guideline as an alternative or additional principle/guideline to promote the mastery of the iconic symbol system. In the next paragraphs a summary of the CTML and the specific guidelines is presented, followed by a theoretical base to ground the potential of this activation guideline as an additional guideline. A variety of activation approaches will be discussed, resulting in a discussion of the experimental research design, a presentation of the results, and a general discussion.

Theoretical Base

Theoretical and empirical base of CTML

Many studies have focused on multimedia learning and put forward empirical evidence that adding for example visual representations to learning materials can improve performance under certain circumstances/conditions (Angeli & Valanides, 2004; Fiore, Cuevas, & Oser, 2003; Lewalter, 2003; Mayer, 2001a; Schwamp & Riempp, 2004). Mayer (2001a, 2001b, 2003, and 2005) presents in this context a Cognitive Theory of Multimedia Learning (CTML), based on information processing models and on three assumptions. The first is the dual channel assumption, meaning that learners have two processing information channels available at the same time: a visual and a verbal channel (Baddeley, 1992, 1995 and Paivio, 1978, 1990, 1991). This assumption explains clearly why adding an extra visual and/or audio representation of materials presented in a text-format fosters the cognitive processing and the development of mental models. The second, the active processing assumption states that learners are active information processors (Cyrs, 1997, Jonassen, 2000, Mayer, 2001a, 2003, 2005 and Wittrock, 1989). This assumption helps to explain why the presentation of learning materials is expected to result automatically in an active processing of the learning content.

The limited capacity, the third assumption states that the capacity of working memory is limited (Chandler & Sweller, 1991; Sweller, 1988, 1989, 1994, 2006), implying that learning from inadequately elaborated learning materials will more rapidly invoke cognitive load since the limitations of working memory are reached in a faster way (Sweller, Van Merriënboer, & Paas, 1998).

Table 1. CTML-guidelines

Guidelines	**Meaning**	**Researches**
The multimedia guideline	Learners benefit more from printed text enriched with pictures than from printed text alone.	Angeli & Valanides (2004) Goolkasian (2000) Guttormsen Schär & Kaiser (2006) Mayer (2003a, 2003b, 2005) Mayer & Gallini (1990) Mayer & Sims (1994) Butcher (2006)
The spatial contiguity guideline	Learning is fostered when printed text and pictures are presented close to one another.	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The temporal contiguity guideline	Learners perform better when pictures and corresponding printed text are presented simultaneously instead of successively.	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The coherence guideline	Learning performance is higher when extraneous sounds, words, pictures are excluded.	Mayer (2003a, 2003b, 2005) Mayer & Moreno (2000) Seufert (2003)
The modality guideline	Learners learn more from animations enriched with audio (narration) than from animations enriched with printed text.	Leahy, Chandler, & Sweller (2003) Mayer (2003a, 2003b, 2005) Mayer & Anderson (1991) Moreno & Mayer (1999)
The redundancy guideline	Learners perform better when presented with animation and narration instead of the combination of animation, narration and printed text.	Mayer (2003a, 2003b, 2005) Mayer, Bove, Bryman, & Tapangco (1996)
The individual differences guideline	All guidelines have a stronger impact with low prior knowledge learners and learners with higher spatial abilities	Mayer (2003a, 2003b, 2005) Mayer, Sobko, & Mautone (2003) Moreno & Duràn (2004) Boucheix & Guignard (2005) Bowen & Roth (2003)

When multimedia learning materials are presented to learners, verbal and/or visual information will be picked up via the sensory system and brought to the working memory via a visual and an auditory channel. In working memory, the information in each channel will be processed until a visual and/or an auditory model has been developed. Organization processes will provoke the integration of both mental models into an integrated model linked to the prior knowledge base in the long term memory (Mayer, 1996). The multimedia elaboration of the learning materials is expected to affect the processing and organization processes that result in visual, auditory and integrated mental models in a direct way.

Table 1 presents an overview of the CTML-guidelines and lists related empirical studies underpinning the positive impact. Apart from a better learning performance, the studies also report a decrease in self-reported cognitive load (Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 1999; Mayer, Steinhoff, Bower, & Mars, 1995; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995). It has to be remarked that Mayer presented the implications of his CTML as ‘principles’. These principles are adopted in the presented study as guidelines to direct the ebaloration of multimedia learning materials.

The theoretical position of the iconic symbol system

A number of authors stress that particular knowledge domains build on specific iconic symbol systems to develop visual multimedia representations (Gilbert, 2005; Gobert, 2005; Kozma & Russel, 2005; Stieff, Bateman, & Utall, 2005). In this context Gemino and Wand (2005) refer to the concept of modelling grammars and how such grammars can differ in degree of complexity. This introduces the assumption that learners need to understand and master these systems – a priori - in order to fully comprehend and/or develop visual representations. Chemistry students need to master for example the chemical symbol systems and molecular representations; engineering students need to understand mathematical formulas and symbols or representations of machinery, biology students need to grasp graphical representations of organs and so forth.

Learners not acquainted with a particular iconic symbol system will experience – in terms of the CTML – intrinsic cognitive load due to the nature of the specific knowledge representations which is too complex. Therefore instructional design should, in part, consider the learner’s experience with the particular knowledge domain being taught (Kalyuga, Ayres, Chandler, & Sweller, 2003). Recent research confirms this finding by stating that the mastery level of the iconic symbol system can have an impact (De Westelinck et. al., 2005; De Westelinck, Valcke, & Kirschner, submitted). Participants studying multimedia learning materials from an unfamiliar knowledge domain obtained significantly lower performance scores and reported higher levels of cognitive load. This implies a mismatch between the prior knowledge level about the iconic symbol system used and the multimedia elaboration of the learning materials (Dobson, 1995, 1999; Goodman, 1976; Lewalter, 2003; Lowe, 2003; Roth, Pozzer-Ardenghi, & Han, 2005; Stenning, 1999; Stern, Aprea, & Ebner, 2003). Only through experience and sufficient practice learners will attain a sufficient mastery level of the iconic symbol system (Dori & Belcher, 2005; Roth, 2003). Some authors put forward a five-step learning path to reach the required mastery level of an iconic symbol system, which is represented in table 2 (Dori & Belcher, 2005; Kozma & Russel, 2005). At a basic level, the learner interprets the symbols as an iconic depiction. This evolves along the following three stages indicated to a final stage where reflective use of the iconic symbol systems becomes possible. The fifth level is considered as the mastery level, the end goal for scientists or student-scientists (see table 2).

Table 2. Competence levels in the mastery of iconic symbol systems

Level 1	Iconic symbol signs as an isomorphic, iconic depiction.
Level 2	Early symbolic skills. The person is familiar with symbolic sign system but they use it without regards to syntax and semantics.
Level 3	Syntactic use of iconic symbol signs.
Level 4	Semantic use of iconic symbol signs.
Level 5	Reflective, rhetorical use of iconic symbol signs.

Since available research indicates that the mastery level of the iconic symbol system can have an effect on performance, more research is needed to study ways to influence this mastery level (De Westelinck, Valcke, & Kirschner, submitted). The present study questions whether a more active involvement of learners in the design of visual representations - implying an active use of the related specific iconic symbol system - is an adequate way to foster the cognitive processing of learning materials and resulting learning performance (Marzano, Pickering, & Pollock, 2001; Simons, van der Linden, & Duffy 2000; Stern, Aprea, & Ebner, 2003; Wileman, 1993). Learners will be invited to (1) develop their own visual representations; thus building upon their personal iconic symbol system, or (2) to build upon half-worked visual representations they can expand or elaborate, or (3) to process fully elaborated visual representations or (4) to process textual learning materials without representations. These four types of multimedia elaborations regarding learning materials are expected to invoke different levels of active engagement by the learner. The highest active engagement is expected to occur when learners have to elaborate completely new visual representations, implying that this will result in a higher processing level of the learning content and the subsequent development of integrated mental models. In the next paragraphs we will discuss the theoretical position of this type of activation in more detail.

The theoretical base of the activation guideline

The activation guideline is introduced in this research as an additional guideline that builds on the active processing CTML-assumption discussed earlier. The activation guideline is expected to foster the inherent active processing and organization of learning content in working memory, in view of the development of mental models. The basic assumption is that the design of learning materials can either promote or hinder this active processing. The basic CTML-guidelines assume that embedding visual representations in learning materials already plays this beneficial role. But several studies have revealed that learners remain passive, though they have been presented with learning materials enriched with embedded visual representations (Bodemer, Ploetzner, Bruchmüller & Häcker, 2005). This can be partly related to the learner's degree of familiarity/acquaintance with the iconic symbol system used, as explained above. An instructional intervention that promotes the active creation of personal visual representations by learners in an explicit way is expected to counter this. This assumption can be labelled as the ‘activation guideline’ and is supported by empirical evidence in a variety of domains. Marzano, Pickering and Pollock (2001) present a meta-analysis of studies that focused on the active construction of non-linguistic representations (NLR) and report effect sizes varying from .5 to 1.3. Though the theoretical base sometimes differs from CTML, these studies share the cognitivist assumptions that the NLR help learners to process information and to develop mental models in working memory and/or help to integrate the mental models in long term memory.

The idea of inviting learners to develop external representations is also related to the theoretical and empirical studies about mind mapping or concept mapping, where learners are asked to develop or elaborate semi-finished mind-maps or to develop their own on the base of a set of design tools, arrows and structures (Novak, 1998). Lewandowsky & Behrens (1999) indicate that the design of concept maps by learners is for example expected to pre-structure knowledge elements in learners, thus reducing the initial complexity of the new knowledge. In other words, ‘extraneous cognitive load’ is reduced when learners are invited to develop this type of visual representations. This helps to orient the selection of subsequent knowledge elements and serves as an organizer. Cognitive load research - in this context - is also helpful to ground instructional interventions that present semi-finished or pre-worked elaborations of visual representations to learners. These elaborations, also called worked examples - have proven to be beneficial to learners (Gerjets, Scheiter, & Catrambone, 2006; Paas & van Gog, 2006; Paas, van Merriënboer, & Adam, 1994; Sweller, 1989, 2006; Sweller & Chandler, 1991; Van Gerven, Paas, van Merriënboer, Hendriks, & Schmidt, 2002; van Gog, Paas, & van Merriënboer, 2006; van Merriënboer, Kirschner, & Kester, 2003).

On the base of a literature review, Van Meter and Garner (2005) structure the different types of activation – described above - along a continuum. At one side of the continuum, visual representations are developed by educational designers and presented as such to the learner (null activation). At the other side of the continuum, completely new visual representations are constructed by the individual learners (full activation). In-between both the types of activation mentioned, the authors’ position ‘worked examples’ of visual representations that consist of semi-finished designs, and where learners are invited to complete the partially elaborated visual representations.

As hypothesized, the ‘activation guideline’ is expected to have an impact on the level of perceived cognitive load. Bodemer and Ploetzner (2002) hypothesize that extraneous cognitive load will be reduced and germane cognitive load will be enhanced when learners are activated to integrate and interrelate learning materials and visual representations. Alternatively, it is also possible that the activation guideline might invoke higher intrinsic and extraneous cognitive load. The attention learners have to pay to the design and development of visual representations – based upon a personal iconic symbol system - could be at the expense of working memory capacity available for building up mental models about the new knowledge elements. This will be especially the case when learners have not yet developed a personal iconic symbol system and/or when they are not acquainted with an available system.

This potentially negative impact is taken into account and countered in the present study by adding an experimental condition to the research design, in which participants are presented with pre-worked visual representations. It is hypothesized that participants presented with pre-worked representations experience a lower level of cognitive load, compared to participants who have to elaborate visual representations independently. Building on findings of previous studies, an alternative hypothesis is presented stating that working with semi-finished visual representations, depends on the mastery level of the iconic symbol system used in the specific representation. If that is not the case, a higher level of cognitive load is experienced by the participants in comparison tot those developing and applying their personal iconic symbol system in a visual representation.

Empirical study

General Research Questions

The central research question of this study is whether the implementation of the 'activation guideline' has a differential impact on learning performances. Building on the theoretical base, the following hypothesis is put forward. Participants studying multimedia learning material will attain higher performance scores on posttests and will report lower levels of perceived cognitive load, depending on the level of activation in the development of visual representations. Subjects will attain higher posttest scores in research conditions in which they are activated. Regarding cognitive load, it is expected that subjects will experience lower levels of cognitive load when they are activated.

Participants

The entire population of freshmen enrolled in the Pedagogical Sciences programme of the faculty of Psychology and Educational Sciences at Ghent University (Belgium) participated in the study (N= 219). Participation was a formal part of the course 'Instructional Sciences' and planned as an advance organizer to a subsequent sessions about the CTML. Informed consent was obtained from all participants prior to experimentation. Prior to the admission to university, almost 95% of the research participants finished General Secondary Education, but by taking different majors. Based on the 2006 analysis of the typical student population in this faculty, we can state that 50% took a major in humanities, 20% graduated with a major in social sciences, and 30% majored in hard sciences. Finally, 5% of the research participants had already attained a bachelor degree.

Research Design

A 4x3 factorial experimental research design was adopted, based on random assignment of participants to different research conditions. Building on a variety of levels of activation, four research conditions were introduced. In each of these research conditions participants studied an alternative multimedia elaboration of the same sets of learning materials. Only the multimedia presentation differed: text only (T); text and ready-made visual representations (T+V), text and pre-worked examples of visual representations (T+PW) and text and the invitation to develop visual representations (T+D). In the text only condition (T), the participants received learning materials consisting of only text, no multimedia representations were embedded. Participants in the condition T+V studied learning materials consisting of text enriched with visual representations. Each part of the text was accompanied by a visual representation of the learning content. These visual representations were developed and presented according to the guidelines formulated by CTML. In the following condition (T+PW), each part of the text was accompanied by pre-worked examples developed and presented following the CTML-guidelines. These examples invited the participants to further elaborate the representations, while engaged in the learning material. In the last condition, full activation was introduced. This implied that participants received learning materials with an open question to develop their own visual representations for each part of the learning materials. Sufficient white space was made available next to each relevant section.

The learning materials in each of the four conditions consisted of four subsequent themes that were related to new, but complex theoretical constructs in the field of educational sciences. Each subset started with the presentation of the learning materials about a certain topic and finished with a posttest, consisting of knowledge and application questions. The knowledge questions measure the retention of content elements; application questions are related to problem solving and test the deeper understanding of the content on the base of information that cannot immediately be retrieved from memory (e.g., Why do we use a task oriented model to design a manual for cleaning a machine?). In the analysis section, the test results are reported separately for each type of questions; in addition a total test score is reported.

Procedure

Participants were randomly assigned to one of the four experimental conditions and studied the learning materials individually. Prior to studying the four subsets of learning materials, a prior knowledge state test was administered as a pretest. After studying each subset, participants filled out a posttest in which their mastery in terms of knowledge and application level was tested. Participants determined individually the pace of their study, and started with each subsequent set of learning materials when they felt they had studied the learning materials thoroughly and/or had solved the posttest.

After studying the learning materials of the first and the second set of materials, participants were also invited to report the perceived cognitive load experienced while studying the materials (Paas, 1992; Tabbers, 2002). In the literature, measurement of cognitive load is mainly based on the learners' subjective report of their perceived mental effort. This results in a subjective cognitive load scale in which learners note the amount of effort they perceived on a scale from 0 to 9 (Paas, Renkl, & Sweller, 2003). Reported use of this type of scale results in high Cronbach's α reliability scores of .82 to .90 (Paas, 1992, Paas, Van Merriënboer, & Adam, 1994).

The answers to the pretest and posttest questions were scored by two independent coders on the base of a correction and scoring key. Test scores were standardized. Scoring reliability was calculated by measuring the percentage person agreement of about 29% of the test items, comparing a first coder’s and a second coder’s scoring (Rourke, Anderson, Garrison, & Archer, 2001). Table 3 indicates high percentages person agreement, ranging between 80% and 97%; with an average of 90.61%.

Table 3. Percentage person agreement in the coding and scoring of the pretest and posttest answers

Set 1		Set 2		Set 3	
Knowledge	Application	Knowledge	Application	Knowledge	Application
90.67 %	86.30 %	94.12 %	95.56 %	94.12 %	97.06 %

Results

Descriptive results

Table 4 presents a summary of the descriptive results. The maximum score for the knowledge and application test is 20 resulting in a total test score of 40. The pretest scores of learners in the four conditions are not significantly different ($F(3,210) = 2.00$, $p = .11$). The low pretest scores of the research participants also indicate that the prior knowledge level about the content of the knowledge domain dealt with in the learning materials was very low to non-existing. In further analyses prior knowledge will therefore not be considered as a co-variable. Due to lack of time for the participants in the conditions where they had to develop or complete visual representations (T+PW and T+D), results about the fourth set of materials are not reported, and the analyses are restricted to the first three subsets. This observation introduces questions about the efficiency of the ‘activation guideline’which will be dealt with in more detail in the discussion section.

The descriptive results in table 4 show that learning performance is in most cases higher when participants developed their own visual representations. Analyses of variance were carried out to compare posttest results and the perceived level of cognitive load. Post-hoc tests reveal specific significant differences between the participants in different conditions. Where relevant, Cohen’s d was calculated to determine the effect size (Talheimer, & Cook, 2002). Table 5 presents a summary of the ANOVA results.

One can observe clear and significant differences between the conditions in relation to the knowledge and application tests in the first and second set of learning materials. This is in contrast to the third set of learning materials were no longer significant differences are observed. An overview of the posthoc results is presented in table 6. In subset 1, both knowledge and application test resulted in significant differences. Participants who developed their own representations (T+D) scored significantly higher on application questions as compared to participants in the text only condition (T) ($d = .61$). A significant difference (participants in T+D condition score higher than participants in T condition) is also found for the total posttest score with an effect size of .70.

Table 4. Mean scores and standard deviations for performance measures and cognitive load

		Text without representations		Text with representations		Completing pre-worked representations		Developing representations		Total score	
		M[a]	*SD*	*M*[b]	*SD*	*M*[c]	*SD*	*M*[d]	*SD*	*M*[e]	*SD*
	Knowledge test	11.99	3.22	12.30	3.87	13.86	4.09	13.52	3.81	12.92	3.82
Set 1	Application test	10.54	4.56	12.29	4.59	11.25	4.48	13.33	4.67	11.86	4.67
	Total test score	22.53	5.77	24.59	6.17	25.10	7.18	26.85	6.56	24.78	6.58
	Knowledge test	10.26	5.90	10.97	5.54	11.42	5.78	13.02	5.63	11.42	5.76
Set 2	Application test	13.89	5.57	13.36	4.65	11.16	5.31	16.09	5.27	13.61	5.46
	Total test score	24.15	9.08	24.33	8.09	22.99	8.87	29.10	7.42	25.03	8.68
	Knowledge test	11.15	5.20	11.46	5.83	11.02	5.86	10.85	6.85	11.12	5.93
Set 3	Application test	6.41	6.41	7.27	5.96	6.30	5.63	5.16	5.29	6.29	5.85
	Total test score	17.56	7.78	18.72	9.96	17.31	9.49	16.01	10.44	17.41	9.46
		M[a]	*SD*	*M*[b]	*SD*	*M*[c]	*SD*	*M*[d]	*SD*	*M*	*SD*
	Cognitive load 1	5.41	1.47	4.81	1.60	4.67	1.60	4.17	1.42	4.76[f]	1.58
	Cognitive load 2	7.00	1.30	6.24	1.43	6.17	1.71	5.83	1.69	6.30[g]	1.59
	Total cognitive load	12.43	2.34	11.07	2.69	10.35	2.99	9.94	2.59	11.07[h]	2.79

[a]*N* = 52. [b]*N* = 55. [c]*N* = 54. [d]*N* = 53.[e]*N*=214.[f]*N*=213. [g]*N*=210. [h]*N*=209.

A comparable result appears when studying the post hoc results in relation to the second set of learning materials. When participants have to develop their own representations (T+D), they obtain higher application posttest scores compared to participants that complete pre-worked examples (T+PW) (d = .93). The same significant difference is found between

T+D and T+PW when studying the total posttest scores (*d* = .60). So the general conclusion is that when participants are fully activated this leads to higher results in the posttest scores.

Table 5. Summary of ANOVA results

		df	*F*	*p*
Set 1	Knowledge	3,210	3.12	0.03*
	Application	3,210	3.76	0.01*
	Total	3,210	4.02	0.01*
Set 2	Knowledge	3,210	2.21	0.09
	Application	3,210	8.09	0.00*
	Total	3,210	6.03	0.00*
Set 3	Knowledge	3,210	0.10	0.96
	Application	3,210	1.19	0.31
	Total	3,210	0.75	0.53
		df	*F*	*P*
	Cognitive load 1	1,209	5.78	0.00*
	Cognitive load 2	1,206	5.09	0.00*
	Total	1,205	7.48	0.00*

* p < .05.

Table 6. Overview of post hoc analysis results and effect-sizes

Set 1	Knowledge	ns	
	Application	T+D > T	F(3,210) = 3.76, df = 3, p < .05; *d* = .61
	Total	T +D > T	F(3,210) = 4.02, df = 3, p < .05; *d* = .70
Set 2	Knowledge	NS	
	Application	T+D > T+PW	F(3,210) = 8.09, df = 3, p < .05; *d* = .93
	Total	T+D > T+PW	F(3,210) = 6.03, df = 3, p < .05; *d* = .60
Set 3	Knowledge	ns	
	Application	ns	
	Total	ns	
	Cognitive load 1	T > T+D	F(1,91) = 5.78, df = 1, p < .05; *d* = .86
	Cognitive load 2	T > T+D	F(1,91) = 5.09, df = 1, p < .05; *d* = .70
	Total cognitive load	T > T+PW	F(1,91) = 7.48, df = 1, p < .05; *d* = .76
		T > T+D	F(1,91) = 7.48, df = 1, p < .05; *d* = 1.01

ns= no significant (post-hoc) results

The results in relation to cognitive load are as expected. The lowest levels of perceived cognitive load were reported by participants that were most actively engaged in the learning materials. Participants in the text only condition (T) reported higher levels of cognitive load as compared to participants in the condition where they had to develop visual representations

(T+D) (d = .86). The same trend is visible for the second reported cognitive load but the effect size is somewhat lower (d = .70). When looking at the total cognitive load (sum of CL1 and CL2) two significant differences are visible. A significantly higher level of cognitive load is reported by participants in the text only condition (T) as compared to participants in the condition using pre-worked examples (T+PW) (d = .76). A significant difference is also found between the text only condition and the condition where participants were invited to develop their own visual representations (T+D) (d = 1.01). The findings help to come to the following conclusion: lower levels of cognitive load are reported when participants are more actively engaged in the learning process.

Discussion

This research aimed at answering the question whether the introduction of the activation guideline resulted in higher performance when studying learning materials that are elaborated on the base of the CTML-guidelines. The results show a congruency between the level of activation in developing visual representations, the resulting level of learning performance, and the level of perceived cognitive load. The highest level of active involvement seems to lead to the highest learning performance and the lowest level of cognitive load. The positive impact is in line with the meta-analysis results as reported by Marzano, et al., (2001) when discussing the active development of non-linguistic representations. More recent studies also confirm the present findings that learner-generated drawing is a strategy that improves learning from text-only materials (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Lowe, 2003; Moreno & Valdez, 2005; Schnotz & Rasch, 2005; Stern, Aprea, & Ebner, 2003; Van Meter, Aleksic, Schwartz, & Garner, 2006; Yoder, & Hochevar, 2005).

Though the elaboration of worked examples did lead to higher learning performance and lower levels of cognitive load, the results were not significant. This contradicts with the results of some researches (Gerjets, Scheiter, & Catrambone, 2006; Moreno, 2006; Van Gerven, Paas, Van Merriënboer, Hendriks, & Schmidt, 2002; Van Gog, Paas, & Van Merriënboer, 2006; Van Merriënboer, Kirschner, & Kester, 2003). These less satisfactory results can be explained by referring to our theoretical base, where we stated that the mastery of the iconic symbol system could be crucial. Since worked examples build already on a specific iconic symbol system (comparable to fully developed visual representation), this implies again that learners should be acquainted with this particular iconic system in the semi-finished representation. Another explanation is that the type of worked examples used in this research can influence their expected impact. Worked examples have been studied frequently. As a result of these studies there is a division between product and process oriented worked examples. This is a clear indication that process oriented worked examples might have a differential impact on novices compared to more experienced learners (Darabi, Nelson & Paas, 2007; Darabi, Nelson & Palanki, 2007).

The fact that merely adding visual representations to the textual learning materials (T+V) did not result in significantly higher learning performance or lower cognitive load is in conflict with typical CTML-research findings. But the findings are in line with previous studies in which the validity of the CTML-guidelines in the social sciences was discussed. The nature of the iconic symbol system used in this knowledge domain is rather descriptive than depictive and the iconic symbol system is less established and mastered to a lesser extent by learners (De Westelinck, et. al., 2005; De Westelinck & Valcke, 2005).

But as stated earlier, the findings are not consistent when comparing the three subsets of learning materials. This can be explained in a number of ways. First it can be argued that we underestimated the impact of individual differences in learners. Cox (1999) stated that the impact of being actively engaged with visual representations might be directly related to individual differences in prior knowledge, cognitive style and so forth. In addition, Mayer's seventh guideline (2001a) also refers to individual differences to explain differences in the validity of the CTML-guidelines. A second explanation is related to the fact that we no longer observe a significant differential effect after studying the third set of learning materials. This could be related to the content (nature and complexity) of the specific learning content in this set. But we could also refer to fatigue setting in. Not all participants were able to finish the fourth set of learning materials. A typical quality of the original CTML-studies 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 participants, during a longer period of time. It is possible that the learning tasks in the current study were more demanding than in Mayer's original studies. This observation is of importance in view of follow-up research. Active engagement in developing visual representations is beneficial, but has to be carefully balanced with time management. This was also suggested by Moreno and Valdez (2005) and Tabbers, Martens and Van Merriënboer (2003) who refer to a lack of time control by participants who are actively engaged in designing representations.

The approach adopted in the experimental research can be criticized from a number of perspectives. A first critique focuses on the quality of the visual representations. But a large team invested much time and effort in the design of the representations which are moreover typical for the approach found in textbooks in the field of educational sciences. The inherent structure of the content theme was clearly and explicitly depicted in the representations. The knowledge and application question in the posttests also focused on these features. The latter is important since recent studies (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. In response to this, it can be argued that the content of the learning materials was comparable to what is found in textbooks and other learning materials in that knowledge domain for novice students. Secondly, the research sample consisted of first year students in the educational sciences. It can be questioned whether the findings can be generalized to students studying in other programs, knowledge domains, and at other educational levels. To further test the hypotheses about the influence of activation on learning performance and cognitive load, larger samples of participants studying in different knowledge domains should be involved. Thirdly, this research took place in a paper/pencil setting while most of Mayer's researched are computer based. It would be interesting to replicate the same research in a computer-based setting. The last remark is related to the results achieved by participants in the condition with pre-worked examples. Although previous research in this matter showed promising results regarding test performance and cognitive load the expectations are not completely fulfilled. This calls for more research building on pre-worked examples in multimedia learning materials.

Considering these remarks, key characteristics of future research can be delineated. Future research should take into account individual differences (Cox, 1999; Kalyuga, Ayress, Chandler, & Sweller, 2003), involve participants from different knowledge domains and different educational levels. Focusing on being and/or becoming familiar with iconic symbol systems, future studies could also centre on extra instructional processes that helps learners to get acquainted with iconic symbol systems (e.g., collaboration) and the complexity level of the learning materials should be taken into account.

Conclusions

The results of the present study suggest that the ‘activation guideline’ is a promising guideline that should be taken into account when studying multimedia learning materials. The research results demonstrate a positive impact on learning performance and a reduction in perceived cognitive load. Post-hoc tests reveal that especially the experimental condition in which participants have to develop their own multimedia representations, results in significantly higher learning performances. Wrapping up the findings and limitations of the present study one can derive clear directions for future research. These directions are in line with the plea of Goldman (2003) to start a second generation of CTML research that is helpful for understanding the affordances of external graphical representations in view of the task demands, and the active processing of learners.

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Chapter 5*

The potential of the collaborative design of visual representations in printed learning materials

Abstract

Evaluative research of Mayer's Cognitive Theory of Multimedia Learning (CTML), points at the critical issue of the mastery of the iconic symbol system to develop and interpret multimedia elaborations. The present study centres – next to training in the interpretation of visual representations - on the evaluation of collaborative design activities when developing visual representations when studying complex novel learning content. Next to a theoretical discussion of the potential of collaboration activities in this context, the results of an experimental research design are discussed. Subsequent a training in the use and interpretation of visual representations, learners were assigned to an experimental collaboration condition or a control condition. The results point at a possible impact of collaboration studying learning materials with text and visual representations.

Introduction

State of the art learning materials rely heavily on the multimedia elaboration of the learning content. Next to text, learning materials are enriched with audio, and/or with other graphical representations such as static and/or dynamic visualizations, such as schemas, tables, graphs, charts, maps, diagrams, pictures, animations, video clips and so forth. In the present study we centre on the potential of enriching learning materials with graphical representations, also referred to as visual representations or graphical models (Gemino & Wand, 2005).

Multimodal learning theories explain how learners process differing representation elaborations of learning materials; for example an audio representation combined with a visual representation of the functioning of an engine. A large body of research is available that centered on the efficacy and efficiency of multimedia representations that build on these theoretical assumptions (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schwan & Riempp, 2004). In addition, these studies point at the efficacy and efficiency of related theories that explain why multimedia representations foster cognitive processing; for example Cognitive Load Theory (Kirschner, 2002; Sweller, Van Merriënboer & Paas, 1998) and the Cognitive Theory of Multimedia Learning (CTML) (Mayer 2001a, 2001b, 2003, 2005). The presented research builds on the CTML as a framework to design the multimedia learning materials and to explain consecutive successful

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learning performance. Although the CTML is supported by a large body of research (Mayer, 2001a, 2001b, 2003, 2005; Mayer & Anderson, 1991; Mayer & Gallini, 1990; Mayer & Sims, 1994; Moreno & Durán, 2004; Moreno & Mayer, 1999), a variety of studies have been less successful to replicate the positive findings. These studies are discussed below and point at the importance to clarify the exact conditions under which multimedia learning materials, developed according to the CTML, lead to higher performance; for example the nature of the knowledge domain and the necessary mastery of the iconic symbol system that has been used when developing visual representations. These studies also call for the definition of additional guidelines. The present study puts forward and evaluates ‘activation’ and, ‘collaboration’ as additional guidelines, next to attention paid to the training of learners in the mastery of the iconic symbol system that is at the base of a visual representation.

It has to be stressed that in Mayers’ orginal CTML, the implications from his theory were presented as principles. These principles are adopted in the context of the present study as ‘guidelines’ to direct the design of multimedia learning materials.

Theoretical Background

Cognitive Theory of Multimedia Learning

Although multimedia has the potential to create high quality learning environments, this promise can become problematic when the conditions that foster learning from multimedia learning materials are not taken into consideration. Norman (1988) states in this context that for any design to be successful, it must build on the needs and interests of the learners and consider their limitations and capabilities . The former was clearly understood by Mayer when developing the Cognitive Theory of Multimedia Learning (CTML). Studies that evaluate the guidelines that are based on the CTML, present clear evidence about their positive impact on knowledge acquisition and transfer of knowledge (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Mayer, 2001a, 2001b, 2003; Mayer & Anderson, 1991, 1992; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer & Gallini, 1990; Mayer & Moreno, 1998, 2000, 2003; Mayer & Sims, 1994; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schwan & Riempp, 2004). Table 1 presents an overview of studies supporting the CTML-guidelines. In addition, information is presented about the nature of the knowledge domain the studies have been set up.

Table 1. Guidelines of CTML

Guideline	Assumption/effect	Researches
The multimedia guideline	Learners benefit more from printed text enriched with pictures than from printed text alone	Angeli & Valanides (2004) Goolkasian (2000) Guttormsen Schär & Kaiser (2006) Mayer (2003a, 2003b,2005) Mayer & Gallini (1990) Mayer & Sims (1994) Schnotz (2002)
The temporal contiguity guideline	Learners perform better when corresponding printed text and pictures are presented simultaneously instead of successively	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The spatial contiguity guideline	Learning is fostered when printed text and pictures are presented close to one another on a page or on screen	Mayer (2003a, 2003b, 2005) Moreno & Mayer (1999)
The coherence guideline	Learning performance is higher when extraneous sounds, words, pictures are excluded	Mayer (2003a, 2003b, 2005) Mayer & Moreno (2000) Seufert (2003)
The modality guideline	Learners learn more from animation enriched with audio (narration) than from animation enriched with printed text	Leahy, Chandler, & Sweller (2003) Mayer (2003a, 2003b, 2005) Mayer & Anderson (1991) Moreno & Mayer (1999) Tabbers, Martens, & Van Merriënboer (2003)
The redundancy guideline	Learners perform better when presented with animation and narration instead of animation and narration combined with printed text matching the narration	Mayer (2003a, 2003b, 2005) Mayer, Bove, Bryman, & Tapangco (1996)
The individual differences guideline	All guidelines have a stronger impact with low prior knowledge learners and learners with higher spatial abilities	Mayer (2003a, 2003b, 2005) Mayer, Sobko, & Mautone (2003) Moreno & Duràn (2004) Roth & Bowen (2003)

The less successful replication of CTM- studies

A number of researchers was less successful to replicate the positive findings of earlier CTML-research. Ploetzner, Bodemer and Neudert (2008) point at research that states that visualizations might even impede learning. A subset of these less successful studies was set up in the field of the social sciences. Application of the CTML-guidelines even led to contradictory results. For example, De Westelinck, Valcke and Kirschner, (2005 and submitted) set up a series of studies in the field of the educational sciences. Application of the CTML-guidelines proved not to be successful. The research pointed – as an explanation for this failure – to the nature and the mastery of the iconic symbol system used to develop multimedia learning materials in the domain of the social sciences. The iconic symbol system determines the way visual representations are developed and used in a specific knowledge domain.

A number of authors stress the critical role of specific iconic symbol systems to develop and/or interpret visual representations (Gilbert, 2005; Gobert, 2005; Kozma & Russel, 2005). Gemino and Wand (2005) refer in this context to the concept of a modelling grammar and how these grammars can differ in degree of complexity. Kirby (2008) and De Westelinck, et al. (ibid) stress that in the social sciences – in contrast to the iconic symbol systems found in biology, physiology, chemistry, physics, … - iconic symbol systems are less established and are hardly part of the knowledge domain being studied. Kirby (2008) gives examples of problems with visual representations: “they may not recognize its relationship to the text (…) may encode it shallowly, (…), interpreting it superficially, (…) misinterpret it.” (Kirby, 2008, p. 171). Especially novices in a knowledge domain might more readily experience shortcomings due to their mastery of the iconic symbol system. This calls for additional research that focuses on developing the mastery of the underlying iconic symbol system. The present study builds on two earlier studies that focused on the potential impact of two new guidelines: the training guideline and the activation guideline. In addition, a new guideline is presented and discussed from a theoretical perspective: the collaboration guideline.

Training to foster the mastery of the iconic symbol system

As discussed earlier, the mastery of an iconic symbol system to develop visual representations, is considered as a critical factor (De Westelinck, Valcke, De Craene, & Kirschner, 2005; De Westelinck, Valcke, & Kirschner, submitted). Several authors state that mastery of an iconic symbol system can only be accomplished when sufficient practice and training are introduced (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005; Roth, Pozzer-Ardenghi, & Han, 2005). In addition, Roth, Pozzer-Ardenghi and Han (2003) and Gilbert (2005) stress that the interpretation of iconic symbol signs is to be seen as a semiotic activity to interrelate three elements: the sign, the referent and the interpretant. Brna, Cox and Good (2001) and Postigo and Pozo (2004) state that this implies active and guided manipulation instead of passive observation. This introduces the need for explicit training focusing on the iconic symbol system. In the literature, authors refer to a five-step learning path to develop the conditional prior knowledge needed to interpret correctly iconic symbol systems and reach a mastery level (Wileman, 1993). At a basic level, the learner interprets the symbols as an iconic depiction which evolves along the next three more stages to a final stage where reflective use of the iconic symbol signs has become possible. The fifth level is considered as the mastery level, the end goal for scientist or student-scientists (Dori & Belcher, 2005). In an earlier empirical study, the impact of training has been studied (De Westelinck & Valcke, submitted). Not all hypotheses about the expected beneficial impact of training could be confirmed. The training in the mastery of an iconic symbol system to develop or interpret visual representations did not result unequivocally in higher learning performance and/or lower cognitive load. Building on the results of this study, the question was raised whether it would not be more beneficial to ask learners to develop a personal iconic symbol system?

Developing 'personal' visual representations: the activation guideline

Research on learning from multimedia builds strongly on multimedia representations developed by experts (Naps et al., 2002). Already Cox (1999) suggested to refocus the attention in multimedia research to studies that centered on the active construction of personal visual representations by learners, in contrast to studying ready-made representations in learning materials. The active construction of representations is hypothesized to foster the development and explicitation of personal iconic symbol systems. At a theoretical level, the activation guideline is consistent with the assumptions of CTML that stress the need for an active processing of (multimedia) learning materials. Activation of the development of external representations is expected to support working memory, to lessen extraneous cognitive load (see below) and to enhance the construction of mental images/schemas to be stored in long-term memory in view. Schnotz and Rasch (2008) refer in this context to the positive impact of 'manipulation' of representations to shift the task difficulty within the learner's zone of proximate development. Learners are therefore requested to develop their own visual representations in relation to new and complex learning materials. Empirical evidence that supports this activation guideline is, for example, found in studies that build on pre-worked examples (Gerjets, Scheiter, & Catrambone, 2006; Paas & Van Gog, 2006; Paas, Van Merriënboer, & Adam, 1994; Sweller, 1989, 2006; Sweller & Chandler, 1991; Van Gerven, Paas, Van Merriënboer, Hendriks, & Schmidt, 2002; Van Gog, Paas, & Van Merriënboer, 2006a, 2006b; Van Merriënboer, Kirschner, & Kester, 2003) and studies that ask learners to develop concept maps (Chang, Sung, & Chen, 2002; Horton, McConney, Gallo, Woods, Senn, & Hamelin, 1993; Novak, 1998; O'Donnel, Dansereau, & Hall, 2002; Van Boxtel, Van der Linden, & Kanselaar, 2000). The results of a series of experimental studies to test the validity of the activation guideline in the knowledge domain of the social sciences by De Westelinck and Valcke (submitted) were partly positive but also called for additional studies to test the activation guideline in subsequent studies. Also Goldman (2008) found that – though he expected self-made representations would be more meaningful and effective to promote learning – this seemed to be a far too simple assumption. Learners seem to be guided by conventional forms to represent their knowledge. Learners also may not have developed a sufficient body of knowledge in the domain to capitalize on the affordances of visuals. In the present study, collaboration was introduced as a potentially beneficial strategy to support the activation guideline and to compensate for the contradictory results found in research thus far.

The theoretical potential of collaboration when developing visual representations

Alternative approaches to foster learning from learning materials could build on small groups, working collaboratively to design and construct the supportive visual representations. A variety of theoretical assumption can be put forward to develop related hypotheses.

Firstly, the approach fits into social constructivist learning models, as for example advocated by the distributed cognition theory. Hutchins (1995) states in this context that learning can be improved when the processing is distributed over several cognitive systems. This could overcome the negative impact of lower levels of prior knowledge as suggested above. Learners have to negotiate meaning, share and compose joint views and construct common knowledge (Hutchins & Klausen, 1996). Hübscher-Younger and Narayanan (2008) refer in this context to constructionism when they state: “If they create multiple representations to explain complex concepts, and share, discuss, and evaluate each other’s representations, all representations may be equally understood (...).” (Hübscher-Younger & Narayanan, 2008, p. 237). The same authors stress the potential of group work that results in a large set of diverse student-created representations, since single representations, even when accurate, are likely to be incomplete (Hübscher-Younger & Narayanan, 2008, p. 242).

In a collaborative setting, visual representations are seen as cultural and communicative tools (Suthers & Hundhausen, 2001; Teasly & Rochelle, 1993). Though collaborative learning is less structured and less teacher-centred, it gives a large autonomy for the students (Bernard & Lundgren-Cayrol, 2001; Henri & Rigault, 1996; Flynn & Klein, 2001; Millis & Cottell, 1998). The former guarantees an activation of the learner when processing new information and constructing knowledge (Jonassen, Lee, Yang, & Laffey, 2005; Van der Linden, Erkens, Schmidt, & Renshaw, 2000). This active involvement reiterates the activation guideline as discussed above. Gillies (2004) argued that collaboration will especially result in higher performance when sufficient structure is provided. This is in line with the advocates of cooperative learning that stress the need to support the clear and shared goal orientation of learners in the collaborative setting (Slavin, 1996). This condition is of importance for the present study when developing the collaborative research conditions, as will be discussed below.

Cognitive load and collaborative learning

Of particular importance - in this context - is the role played by cognitive load. Cognitive processing of learning materials invokes intrinsic, extraneous and germane cognitive load (Chandler & Sweller, 1991, 1996). Whereas the intrinsic cognitive load is a reflection of the complexity and difficulty of the content, extraneous cognitive load is related to the way the materials are represented. Germane cognitive load is related to the load invoked by the cognitive processing of information and the construction of schemas (Sweller, Van

Merriënboer & Paas, 1998). It is the aim of instructional designers to reduce extraneous cognitive load and to foster germane cognitive load. These assumptions are central to the traditional CTML-guidelines and have proven to be successful to reduce extraneous cognitive load (Kalyuga, Chandler, & Sweller, 1999; Mayer, Steinhoff, Bower & Mars, 1995; Mousavi, Low, & Sweller, 1995). A typical and successful approach to reduce extraneous cognitive load has been to present worked examples to learners (Meverach, Z. & Kramarski, B., 2003; Sweller, 2006; Van Gerven, Paas, Van Merriënboer, & Schmidt, 2002).

The question is how cognitive load is affected when we invite learners to develop visual representations in a collaborative setting? Conflicting theoretical assumptions can be derived from the theory when answering this question. According to CTML, the collaborative development of visual representations might confront learners with the limited capacities of their working memory and hence hinder the construction of new mental models in working memory. The input from other learners that present their own iconic symbol systems representation systems is expected to lead to a too high number of information input to be selected, organized and processed in a focused way. An alternative hypothesis can be put forward. Learners that have to work individually to develop and apply a novice iconic symbol system will experience a higher level of cognitive load as compared to learners who are offered a variety of examples of visual representations from fellow learners. These examples help to develop and apply the personal iconic symbol system and the related visual representations.

Research

General research questions and hypotheses

The central question of this study is what the validity is of basic and additional CTML-guidelines when studying multimedia learning materials in a collaborative setting. Therefore, all the experimental conditions in the present setting build on a collaboration between learners when studying alternative elaborations of learning materials and/or when they receive additional training in relation to the active manipulation of visual representations.

Building on the theoretical base discussed above about the potential of ‘activation’ and the need for ‘training’, the following hypotheses are put forward:

- Learners studying learning materials will attain higher knowledge and application test results when they are actively engaged in the development of visual representations and/or after receiving training to do so.
- Learners studying learning materials will report lower levels of cognitive load when they are actively engaged in the development of visual representations and/or after receiving training to do so.

Though the process variable ‘collaboration’ is not manipulated in the present study, we nevertheless expect that studying the materials in a collaborative setting will boost the cognitive processing of learners in conditions were they have to develop their own visual representations and this in contrast to conditions were expert made visual representations are presented to learners.

Participants

Participants involved in the study were enrolled (2003-2004) as freshmen in the Pedagogical Sciences program of the faculty of Psychology and Educational sciences of Ghent University (Belgium). The entire population of freshmen participated in the study (N=217). Participation was a formal part of the course ‘Instructional Sciences’. Informed consent was obtained from all participants prior to experimentation. Nearly 95% of these students enrolled in Educational Sciences after finishing a general secondary education career. Most of these students opted in their secondary education for a humanities and social sciences orientation; to a lesser extent these students studied hard sciences at secondary school level.

Research Design

A pretest posttest experimental design was set up, based on four experimental conditions. The pretest helped to determine the prior knowledge level of the participants. Posttests were presented after each subset of learning materials. Pre- and posttests consisted of knowledge and application questions. Knowledge questions focused on remembering elements of a topic (e.g., What is the central point in the learning style concept of Witkin?). Application questions focused on problem solving and tested the deeper understanding of the content (e.g., Which learning style – according to Vermunt - is applicable to yourself? Illustrate with examples.).
Four experimental conditions were designed and implemented to investigate the differential impact of varying approaches to the integration of visual representations in learning materials. A shared feature of these conditions is that they all were set up in a collaborative setting: text only (T), text and visual representations (T+V), text and development of visual representations (T+D) and text and development of visual representations after training (T+D after training). In the condition text only (T), groups of participants studied textual learning materials, not enriched with visual representations. Participants in the condition T+V studied collaboratively learning materials consisting of text enriched with visual representations. Each part of text was accompanied by a ready-made visual representation, related to the textual information. In the T+D condition, small groups of participants were invited to develop their own visual representations and to share these with the group members. In the last experimental condition, T+ D after training, groups of participants were invited to develop their own visual representations but after they were involved in a training to develop visual representations. Participants were assigned randomly to one of the four conditions.

Nature of the training

Based on earlier research it is argued that familiarity and acquaintance with the used iconic symbol system is an influencing factor (De Westelinck & Valcke, 2005; De Westelinck, Valcke, De Craene, & Kirschner, 2005; De Westelinck, Valcke, & Kirschner, submitted). This can be fostered by training participants in the use of iconic symbol system. Training is a concept that is widely in use in on-the-job related context (Acemoglu & Pischke, 1998; Loewenstein & Spletzer, 1998; Tziner, Fisher, Senior, & Weisberg, 2007). As companies see the importance of human capital they invest much in training. In the literature, authors refer to a five-step learning path to develop the conditional prior knowledge needed to interpret correctly iconic symbol systems and reach the mastery level of iconic symbol system (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005; Roth, 2003; Roth, Pozzer-Ardenghi, & Han, 20005; Wileman, 1993). At a basic level, the learner interprets the symbols as an iconic depiction which evolves along the next three more stages to a final stage where reflective use of the iconic symbol signs has become possible. The fifth level is considered as the mastery level, the end goal for scientist or student-scientists (Dori & Belcher, 2005; Kozma & Russel, 2005).

Based on the former, it can be argued that training learners in the skill of visualization and the iconic symbol system might be beneficial to the performance of the learners. If learners are taught how to handle the iconic symbol system, cognitive load might decrease and learner performance might increase. Gilbert (2005) states that the skills improve through relevant experience after training. This was confirmed by Kozma and Russel (1997) when the emphasis is on the importance of the development of such skills. Other authors came to the same conclusions (Brna, Cox, & Good, 2001; Bowen & Roth, 2002; Roth, Pozzer-Ardenghi, & Han, 2005; Roth, Bowen, & Masciotra, 2005). In the past, a lot of training was set up to train social skills (Beelman, Pfingsten, & Lösel, 1994; Michelson, Sugai, Wood, & Kazdin, 1983; Schneider & Byrne, 1985), in work-related context (Loewenstein & Spletzer, 1998; Tziner, Fisher, Senior, & Weisbert, 2007) but also in educational settings training was introduced (Briars & Larkin, 1984).

In the present research, participants in a particular condition received a training to develop their own iconic symbols. Participants were taught a variety of iconic symbol sign approaches. After this introductory part, they got the opportunity to practice the use of iconic symbol systems in relation to a text, that reflected a comparable difficulty level as compared to the texts in the learning materials used in the subsequent research phases.

Learning materials

Four parallel sets of learning materials, each consisting of three subsets, were developed to be presented in each of the research conditions. To guarantee the optimal design of the multimedia elements in the learning materials, Mayer's principles were strictly taken into account when developing the sets of materials (2001a, p. 191-193).

Procedure

Participants started by completing individually the prior knowledge test. Next, they studied the learning materials in small groups (N = 4). The groups were invited to study the learning materials, discuss the content, and explain this to one another. When visual representations were required to be developed, they were invited to build up and share multiple visual representations but were also invited to develop a single final shared representation to be added to the specific subset of learning materials.

After studying a specific subset of the learning materials, participants completed individually a posttest related to this subset. Additionally, after the first and second subset of materials, participants were also asked to report individually their experienced cognitive load when studying these materials. In the literature, measurement of cognitive load is mainly based on the learners' subjective report of their perceived mental effort. This results in a subjective cognitive load scale (Paas, Renkl, & Sweller, 2003) in which students note the amount of effort they experienced on a scale varying from 0 to 9. Reported use of this type of scale results in high Cronbach's α reliability scores of .82 to .90 (Paas, 1992; Paas, Van Merriënboer, & Adam, 1994).

The answers on the knowledge and application questions were scored on the base of a correction and scoring key. Test scores were standardized, with a maximum score of 20 for each pre- and posttest. Two trained, independent scorers judged the answers to the open questions. Inter-rater reliability was calculated to control the quality of the scoring on 25% of the test answers (Rourke, Anderson, Garrison, & Archer, 2001). A person agreement of 83.33%, reflecting high reliability, was calculated. In the results section, posttest results in relation to the different subsets of learning materials are reported for each research condition. On average, the total experiment lasted about 20 minutes.

Research results

Descriptive results

The descriptive results are summarized in table 2. It is obvious from the table that in research conditions where the participants are invited to develop visual representations, the participants mostly attain higher performance levels. As to cognitive load, it is clear that the participants in the condition T+D report the lowest level of cognitive load. Pretest scores were consistently low for participants in all research conditions. No significant differences in pretest scores were observed. Therefore, pretest scores were not included in the subsequent analyses.

The impact of developing visual representations

The first hypothesis stated that participants, studying multimedia learning materials in a collaborative setting will attain higher posttest scores when they were actively engaged in the development of visual representations and/or when they received additional training to do so. By and large, the descriptive results in Table 2 suggest that this hypothesis is to be accepted. Analyses of variance was carried out to test the hypothesis. In case of statistically significant differences, Cohen's *d* was calculated to determine the effect size (Talheimer & Cook, 2002). Table 3 summarizes the ANOVA-results and table 4 summarizes the post hoc results.

Clear and significant differences are found in the first set of learning materials in relation to the knowledge questions, application questions and the total test score.

After studying the first set of learning materials, significantly higher knowledge test scores are attained by participants that were asked to develop their own visual representations (T+D) as compared to participants that were asked to develop their visual representation after receiving training (*d* = .83). Participants studying learning materials with embedded visual representations (T+V) attain significantly higher application test scores than participants studying text only (T) learning materials (*d* = .52). The same trend is observed in relation to the total test score. Studying text only (T) resulted in significantly lower performance than studying text with embedded visual representations (T+V) (*d* = .45). Participants in the condition where they were asked to design visual representations (T+D) scored significantly higher than those in the text only (T) condition (*d* = .51).

In relation to the second set of learning materials, significantly higher knowledge test scores are observed when participants study learning materials with embedded visual representations (T+V) as compared to participants studying text only (T) learning materials (*d* = .74). Additionally, participants studying text with embedded visual representations (T+V) attained significantly higher knowledge test scores than participants who had to develop (T+D) the visual representations (*d* = .94). Participants that were asked to develop visual representations after receiving a training (T+D after training) attained significantly lower knowledge test scores than participants studying learning materials with embedded visual representations (*d* = .99).

Table 2. Descriptive results

		Text without representations		Text with representations		Developing representations		Developing representations with training		Total score	
		M[a]	*SD*	*M*[b]	*SD*	*M*[c]	*SD*	*M*[d]	*SD*	*M*[k]	*SD*
Set 1	Knowledge test	9.63	3.23	10.25	3.58	11.17	4.31	8.41	1.83	9.90	3.49
	Application test	9.67	4.13	11.63	3.44	11.17	3.37	11.46	3.67	10.88	3.77
	Total test score	19.30	6.09	21.88	5.27	22.34	5.88	19.88	4.17	20.78	5.62
Set 2	Knowledge test	10.37	3.27	12.83	3.39	9.58	3.55	9.43	3.44	10.70	3.64
	Application test	9.55	1.61	9.77	1.14	10.03	2.39	9/93	2.28	9.79	1.84
	Total test score	19.93	3.87	22.61	3.58	19.61	4.83	19.36	4.31	20.49	4.29
Set 3	Knowledge test	11.69	9.02	11.75	9.24	10.80	9.78	13.90	8.61	11.93	9.17
	Application test	14.49	7.28	14.88	6.35	16.06	6.36	13.96	8.00	14.84	6.98
	Total test score	26.18	13.56	26.63	11.35	26.86	11.11	27.87	9.50	26.77	11.68
		M	*SD*	*M*[b]	*SD*	*M*[c]	*SD*	*M*[d]	*SD*	*M*	*SD*
	Cognitive load 1	5.04	1.62	4.42	1.56	4.40	1.53	3.73	1.47	4.48	1.60
	Cognitive load 2	6.07[e]	1.77	5.21[f]	1.61	5.58[g]	1.45	4.68[h]	1.80	5.46[i]	1.73
	Total cognitive load	11.13[e]	3.07	9.62[f]	2.95	9.93[g]	2.75	9.93[h]	2.83	9.93[i]	3.07

[a]*N* =69. [b]*N* = 60. [c]*N* = 47. [d]*N* = 41. [e]*N*= 67. [f]*N*= 58. [g]*N*= 45. [h]*N*= 40.[i]*N*=210.[k]*N*=217.

Table 3. ANOVA-results

		df	*F*	*p*
	Knowledge	3,213	5.17	0.02*
Set 1	Application	3,213	3.69	0.01*
	Total	3,213	4.09	0.01*
	Knowledge	3,213	11.75	0.00*
Set 2	Application	3,213	0.72	0.54
	Total	3,213	7.52	0.00*
	Knowledge	3,213	0.89	0.45
Set 3	Application	3,213	0.75	0.52
	Total	3,213	0.18	0.91
		df	*F*	*P*
	Cognitive load 1	3,213	6.26	0.00*
	Cognitive load 2	3,206	6.50	0.00*
	Total	3,206	7.77	0.00*

Participants studying materials with embedded visual representations (T+V) attain significantly higher total test scores as compared to participants studying text only (*d* = .72), or participants developing their own representations (*d* = .70), or participants developing their own representations after receiving training (*d* = .82).

In relation to the third set learning materials, no significant differences in test scores were observed.

The impact on cognitive load

The descriptives in table 2 already point at clear differences in reported cognitive load (CL), considering the different experimental conditions. Participants invited to develop their own visual representations after receiving training, reported the lowest levels of cognitive load. The analysis of variance results point consistently at a significantly higher cognitive load when participants were asked to study text only learning material (T). In every case, high effect sizes are observed.

Table 4. Post-hoc results

Set 1	Knowledge	T+D > T+ D after training	*F*(3,213) = 5.17, *df* = 3, *p* < .05; *d* = .83
	Application	T+V > T	*F*(3,213) = 3.69, *df* = 3, *p* < .05; *d* = .52
	Total	T +V > T	*F*(3,213) = 4.09, *df* = 3, *p* < .05; *d* = .45
		T+D>T	*F*(3,213) = 4.09, *df* = 3, *p* < .05; *d* = .51
Set 2	Knowledge	T +V > T	*F*(3,213) = 11.75, *df* = 3, *p* < .05; *d* = .74
		T +V > T+D	*F*(3,213) = 11.75, *df* = 3, *p* < .05; *d* = .94
		T +V > T+D after training	*F*(3,213) = 11.75, *df* = 3, *p* < .05; *d* = .99
	Application	NS	
	Total	T +V > T	*F*(3,213) = 7.52, *df* = 3, *p* < .05; *d* = .72
		T +V > T+D	*F*(3,213) = 7.52, *df* = 3, *p* < .05; *d* = .70
		T +V > T+D after training	*F*(3,213) = 7.52, *df* = 3, *p* < .05; *d* = .82
Set 3	Knowledge	ns	
	Application	ns	
	Total	ns	

	Cognitive load 1	T > T+D after training	*F*(1,213) = 5.78, *df* = 1, *p* < .05; *d* = .86
	Cognitive load 2	T > T+D after training	*F*(1,206) = 5.09, *df* = 1, *p* < .05; *d* = .70
	Total cognitive load	T > T+V	*F*(1206) = 7.48, *df* = 1, *p* < .05; *d* = .76
		T>T+Vafter training	*F*(1,206) = 7.48, *df* = 1, *p* < .05; *d* = 1.01

Discussion

The impact on test performance

In the present study, a variety of guidelines to develop visual representations were tested in a shared collaborative learning context. Next to participants, studying in a small group learning materials in a text only condition, other participants were invited to study collaboratively learning materials enriched with expert-made visual representations. And, building on earlier studies that suggested the potential of inviting learners to develop their own visual representations, a third group shared and discussed the development of visual representations. In a fourth condition, the collective development of visual representations was preceded by a group training. Activation and training were introduced to foster the mastery of the iconic symbol system that is at the base of a visual representation. Collaboration was expected to be a catalyst to boost up learning performance in conditions were participants were invited to develop their own visual representations.

At a first level, it is clear that collaboratively studying ‘text only’ learning materials leads rather to lower performance. This is in line with the findings of most CTML-studies. A second key finding is that participants who study collaboratively learning materials that have been enriched with expert-made visual representations (T+V), attain in most conditions significantly higher test scores (knowledge test, application test or total test score).

The analysis results do not confirm the potential of inviting participants to develop their own representations (T+D); nor the expected additional positive impact of training participants in such a research condition (T+D after training). These results are unexpected; especially considering the fact that participants were expected to benefit additionally from the collaborative set-up of the learning activity. Although unexpected, the results are in line with previous research (Prangsma, 2007, in press). A number of explanations can be put forward. Suthers and Hundhausen (2003) argue that the choice of representational notations has an influence on the learners' interaction and as such on the collaboration. Individual differences are therefor expected to play a mediating role. For instance, when studying the use concept maps, Kinchin and Hay (2004) hypothesized that groups would be more effective when group members were chosen on the base of shared knowledge structures. So this implies that the group composition might be an influencing factor. We can also doubt the status of the hypothesis about the potential of sharing and discussing visual representations. It is recognized that students learn scientific meanings and concepts by using them in oral communication (Duit & Treagust, 1998; Lemke, 1990; Palincsar, Anderson, & David, 1993). Collaborative design of visual representations gives the participants the opportunity to articulate their thoughts, elaborate the meaning of the content and co-construct conceptual understanding. However it is possible that the design task might not be as provocative as hoped; this leading to lower performance (see also Van Boxtel, Van der Linden, Roelofs, & Erkens, 2002). A third element can be put forward to explain the less beneficial impact of developing visual representations. In the present study, we used high perceptual and cognitive challenging learning materials that could have induced an 'overwhelming' effect. This concept, introduced by Lowe (2004), refers to the cognitive costs of the learning materials which might be too high and lead to learners not focusing on visual representations (Lowe, 2003; Pane, Corbett, & John, 1996). 'Underwhelming' is a related concept and is observed when learners do not really engage in the comprehension of the visual representations. Additionally, Dillenbourg and Bétrancourt (2006) also warn about the supplementary cognitive costs, caused by the processes invoked by the collaboration. While collaboration might facilitate learning, it also requires cognitive resources. When too many resources are required, the actual organization of mental models is stalled. There seems to be a thin line between *facilitating* learning and *hindering* learning. A last explanation to explain the less favourable outcomes builds again on the nature of the iconic symbol system as being part of the knowledge domain. To design visual representations in relation to a new knowledge domain, the learner needs also to master the particular iconic symbol system that fits this knowledge domain. The basic mastery level of the participants could simply have been inadequate to develop visual representations. A clear indicator as to the latter was the very low pretest levels of all participants in this study. This reintroduces the literature that stresses the needs to reach a basic mastery level of the iconic symbol system (Roth, 2003; Roth, Pozzer-Ardenghi, & Han, 2005). Developing this mastery requires a learning process with sufficient opportunities to exercise this skill. The groups or learners in the present study might have been to heterogeneous as to this learning process.. Another fact is that being a novice in the use of an iconic symbol system also leads to more time being spent on developing visual representations. This might have caused participants to neglect the cognitive processing of the actual learning content, thus leading to lower test performance. Lastly, we did not check whether the participants in the present study were sufficiently acquainted with collaborative learning. The collaboration-literature stresses in this context the importance to develop collaboration skills (see e.g., Johnson & Johnson, 1996).

In the fourth condition, training was added as a guideline to counter the negative effect of a weak mastery of the iconic symbol system. The goal was to train the participants in the skill of using the iconic symbol system fit for the knowledge domain of the educational sciences. Tziner, Fisher, Senior and Weisberg (2007) indicate that student characteristics can influence the learning outcomes. The authors refer to conscientiousness, self-efficacy, motivation to learn, learning goal orientation, performance goal orientation and instrumentality of training. This might lead to lower mastery levels of the iconic symbol system, thus resulting in lower test performance.

A last observation centers on the non- significant results in relation to the third set of learning materials. This might be due to fatigue. Issues that were raised above about the importance of active engagement, sufficiently high levels of cognitive processing can be repeated in this context.

The impact on cognitive load

Whereas, the impact on test performance is not in line with the theoretical expectations, the results in relation to cognitive load are more promising. Participants in conditions where they were actively engaged with visual representations, resulted in the lowest levels of cognitive load. This is in line with other researches (Bodemer Ploetzner, Feuerlein, & Spada, 2004; De Westelinck & Valcke, submitted; van Meter, Aleksic, Schwartz, & Garner, 2006; Yoder & Hochevar, 2005).

Limitations, recommendations and conclusions

A number of methodological questions can be raised in relation to the present study. Firstly – as was explained earlier – the process variable ‘collaboration’ was not manipulated in this present study. This would have required a more elaborated research design to contrast groups and individuals working in eight parallel conditions. This was not feasible in the specific course setting adopted for this study, and would have required a higher number of available research participants. Secondly, questions can be raised about the content and the difficulty level of the specific learning content. This could have played a role when comparing the three sets of learning materials. Thirdly, differences in the impact of CTML-guidelines can also be related to the differences between the present study and the original CTML-studies of Mayer and his colleagues. Their studies tend to be rather short. Experimental sessions of 180 seconds are no exception. Longer studies, implying the processing of larger set of learning materials can be cognitively more demanding. Also Tabbers, Martens and van Merriënboer (2003) mention differences in duration as a possible explanation for diverging and inconsistent research findings. A critical issue is the fact that individual differences of participants 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. Nevertheless, also Mayer (2001a) points at the mediating impact of individual differences; such as for example spatial abilities. He also concludes that visual 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. Building on the methodological remarks, basic characteristics of future studies can be outlined. Future research should take into account variables related to individual differences (Cox, 1999; Kalyuga, Ayress, Chandler, & Sweller, 2003). Comparison between freshmen and more advance undergraduate and graduate students could be set up. This would allow to study the mediating impact of the mastery of the knowledge domain, and the mastery of the typical iconic symbol system when implementing specific CTML and alternative guidelines.

In summary, the present study reconfirmed a number of findings of earlier studies about the impact of visual representations. But, the study was not able to put forward convincing evidence to ground the theoretical assumptions about learners that develop their own visual representations. In addition, the collaborative nature of the learning activities – a shared feature in all the research conditions - did not result in an added-value to ground instructional practices. More research is needed to unravel the differential impact of the variables introduced in the present study.

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Chapter 6*

Processing visual representations: do training and activation help?

Abstract

In an experimental design, 217 participants were randomly assigned to experimental conditions to study multimedia learning materials: text only (T), text and visual representations (T+V), text and individual development of visual representations (T+D) and text and individual development of visual representations after training (T+D after training). The study was set up to enrich the design implications derived from the Cognitive Theory of Multimedia Learning. The central research problem centres on the question whether training in view of mastery of the underlying iconic symbol system of a visual representation and/or activation by inviting students to develop their own visual representations result in effective cognitive processing of the learning materials. The hypotheses as to the expected impact of activation and training could not be confirmed. The results reflect inconsistencies when compared to other studies. They also point at the critical role of prior knowledge when studying a new knowledge domain.

Introduction and general research problem

It is not possible to neglect the importance of multimedia in the current design and development of learning materials. Textual learning materials are enriched with pictures, graphs, visual elements and audio materials. In the present study, we centre on a particular subset of multimedia elements added to learning materials, namely static, visual multimedia elements, referred to as visual representations.

Visual representations do not only affect the attractiveness of learning materials but are also expected to influence the active processing of the learning content. The latter is the central assumption of the Cognitive Theory of Multimedia Learning (CTML) as defined by Mayer and colleagues (Mayer, 2001a, 2001b, 2003, 2005; Mayer & Anderson, 1991, 1992; Mayer & Moreno, 1998, 2000, 2003; Mayer & Sims, 1994). The CTML resulted in a characterization of design guidelines. A large body of empirical evidence underpins the assumptions about the about of the CTML-guidelines, resulting in higher learning performance (see e.g., Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003). But it has to be stressed that

* Chapter six is based on (1) De Westelinck, K., & Valcke, M. (2005). The impact of external graphical representations in different knowledge domains: is there a domain specific effect? In L. Verschaffel, E., De Corte, G. Kanselaar, & M. Valcke (Eds.). *Designing powerful learning environments to promote deep conceptual and strategic learning in major curricular domains* (pp. 213-232). Leuven, Belgium: Studia Paedagogica - Leuven University Press and (2) the article submitted to *Learning and Individual differences.*

most of these empirical studies have been set up in the field of the 'hard sciences' (chemistry, physics,..). Comparable research, set up in the field of the social sciences has been less successful to replicate the CTML-findings, leading to unsolved issues concerning CTML in other knowledge domains. A number of researchers discuss these inconsistencies. Scaife and Rogers (1996) state that there is insufficient knowledge about cognitive structures and processes to develop a full understanding of learning processes related to visual representations. Postigo and Pozo (2004) argue that different levels of expertise ask for different treatment which is ignored in many researches. According to Guttormson Schär and Kaiser (2006) the impact of studying multimedia learning materials has to be evaluated in relation to the initial learning goals. Other researchers stress the importance of individual differences, cognitive load and design issues (Dutke & Rinck, 2006).

An alternative explanation to approach the conflicting empirical results, is studying the mastery of the iconic symbol system that is at the base of visual representations in a particular knowledge domain, also called 'symbolic literacy' (Eskritt & Lee, 2007). As synonyms for 'iconic symbol systems', authors use concepts such as 'notations' or 'permanent external symbols'. Iconic symbol systems differ depending on the knowledge domain. Certain knowledge domains (such as chemistry, biology, mathematics, …) build on well-defined, widely used and conventionalized unambiguous iconic symbol systems to represent specific content and can be considered as building bricks of this particular knowledge domain (Aldrich & Sheppard, 2000; Gilbert, 2005; Gobert, 2005; Kozma & Russel, 2005; Roth, Pozzer-Ardenghi, & Han, 2005; Stieff, Bateman, & Utall, 2005). In contrast, other knowledge domains, such as the social sciences, do not build on established iconic symbol systems. Mastery of an iconic symbol system can only be achieved through experience and practice (Dori & Belcher, 2005; Gilbert, 2005; Gobert, 2005; Kozma, & Russel, 2005; Stieff, Bateman, & Utall, 2005). Weak mastery of a less developed iconic symbol system can therefore lead to subsequent lower performance on performance tests. In an earlier study, we attempted to influence the mastery of the iconic symbol systems by evoking a more active and conscious processing (refereed to as activation) of the visual representations in the knowledge domain of the social sciences (De Westelinck & Valcke, submitted). Although in some cases activation resulted in higher learning performance, also inconsistent results were found. Therefore, in the present study activation is again addressed as the central research focus, but more attention will be paid to the influence of training on the active engagement of participants in the processing of visual representations.

The theoretical position of activation

Previous research could not consistently replicate the positive impact of the CTML-guidelines in the domain of the social sciences. It was therefore hypothesized that this could be related to the weak mastery of the iconic symbol system applied by instructional designers when developing the visual representations (De Westelinck, et. al., 2005). Activation was introduced in a variety of studies to foster higher active engagement of learners when processing the learning materials (Gerjets, Scheiter, & Catrambone, 2006; Paas & Van Gog, 2006; Van Gog, Paas, & Van Merriënboer, 2006; Van Merriënboer, Kirschner, & Kester, 2003). The introduction of the activation guideline can be justified on the base of CTML since this theory builds on the active processing assumption. This assumption states that learners – automatically – are engaged in selecting, organizing and integrating mental models when studying learning materials (Mayer, 2003). A number of authors have suggested ways to foster this active processing (Bodemer, & Ploetzner, 2002; Van Hout-Wolters, 2000;).

Activation is not to be seen as a dichotomy (no activation versus activation) but rather as a continuum (Van Meter & Garner, 2005; Van Meter, Aleksic, Schwartz, & Garner, 2006). At one side of the continuum, visual representations are completely developed by instructional designers and presented as such to the learner (null activation). At the other side of the continuum, visual representations are constructed independently by the individual learners (full activation). Activation is expected to influence cognitive load. In this context it is important to study the influence on germane and extraneous cognitive load. When learners do not master the iconic symbol system used to develop visual representations in a particular knowledge domain, cognitive load will be higher and consequently the working memory capacities will be affected. This will hinder the construction of mental models. Ideas, based on empirical and theoretical evidence, to cope with cognitive load and to reduce extraneous cognitive load concentrate on varying the levels of activation; for example by presenting complete or worked examples (Brünken, Steinbacher, Plass, & Leutner, 2002; Kirschner, 2002; Lowe, 2003; Mayer, 2003; Van Merriënboer, Kirschner, & Kester, 2003). Bodemer and Ploetzner (2002) found that extraneous cognitive load was reduced and germane cognitive load was enhanced when learners were actively engaged in developing visual representations. But, in contrast to the former theoretical discussion, an alternative hypothesis can also be put forward. Developing visual representations takes time and requires part of the capacity of working memory to develop schemas. It is possible that especially novices (e.g., freshman at university) might experience problems since the active processing of new and complex learning content might be negatively affected by the additional task to design external visual representations. This introduces the hypothetical role of training to counter the negative side-effects of requiring learners to develop external visual representations.

Theoretical assumptions about the impact of training

In our previous studies argue that familiarity/acquaintance with the iconic symbol system could be a critical factor influencing the learning outcomes when studying multimedia learning materials (De Westelinck & Valcke, 2005; De Westelinck, et. al., 2005; De Westelinck, Valcke, & Kirschner, submitted). The concept of mastery level was introduced by several authors when they argued that it can only be accomplished when practice and training are introduced (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005; Roth, Pozzer-Ardenghi, & Han, 2005). Roth, Pozzer-Ardenghi and Han (2003) and Gilbert (2005) define the interpretation of iconic symbols as a semiotic activity in which three different elements interrelate: the sign, the referent and the interpretant. They build on the earlier work of de Saussure and Ecco who developed grounding work in the field of semiotics. Brna, Cox and Good (2001) and Postigo and Pozo (2004) state that this implies active and guided manipulation instead of passive observation. This introduces the need for explicit training focusing on the iconic symbol system. In the literature, authors refer to a five-step learning path (see Table 1) to develop the conditional prior knowledge needed to interpret correctly iconic symbol systems and reach a sufficient mastery level (Aldrich & Sheppard, 2000; Dori & Belcher, 2005; Kozma & Russel, 2005). At a basic level, the learner interprets the symbols as an iconic depiction, which next evolves along three stages to a final stage where reflective use of the iconic symbol signs becomes possible. The fifth level is considered as the mastery level, the final goal for scientist or student-scientists. This development path is also reflected in the theoretical position of Wileman (1993). He refers to visual thinking when discussing the mastery of iconic symbol systems. Visual thinking is defined as 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. Three overlapping strategies of thought are distinguished: imaging, seeing and designing. And also three types of visual representations are being observed: pictures, verbal symbols and graphical symbols.

Some authors discuss design features of the training. For instance, the training should include sufficient opportunities to exercise the new skills (Gilbert, 2005; Kozma & Russel, 1997). Other authors suggest the adoption of comparable approaches (Brna, Cox, & Good, 2001; Bowen & Roth, 2003). In this context, Schunn and Anderson (1999)conclude that a clear distinction can be made between experts and novices. Different levels of expertise can be observed along a continuum, pointing at the gradual increase and integration of knowledge and skills.

Table 1. Competence levels in the mastery of iconic symbol systems

Level 1	Iconic symbol signs as an isomorphic, iconic depiction.
Level 2	Early symbolic skills. The person is familiar with symbolic sign system but they use it without regards to syntax and semantics.
Level 3	Syntactic use of iconic symbol signs.
Level 4	Semantic use of iconic symbol signs.
Level 5	Reflective, rhetorical use of iconic symbol signs.

In contrast to CTML, stating that extraneous cognitive load is expected to be lower due to he support received by adding visual representations, the present discussion about the mastery of the iconic symbol system introduces a critical prior condition. Extraneous cognitive load will only be reduced when the learner masters, in a sufficient way, the specific iconic symbol system used to develop a visual representation. Consequently, emphasis should therefore not only be on the multimedia nature of learning materials as stated by the original CTML, but also on the mastery level of the iconic symbol system. If learners do not sufficiently master the iconic symbol system in a new or unfamiliar knowledge domain, the visual representations might invoke a higher extraneous cognitive load, thus leading to poorer learning. To counter this, training can be introduced. If learners are taught how to interpret and develop an iconic symbol system, cognitive load might be decreased and learning performance increased.

In the literature, authors discuss the differential impact of training on learning performance (Chmielewski & Dansereau, 1998). Although we expect that training is beneficial considering the resulting mastery of the iconic symbol system, there might also be a drawback. Investing time and energy in developing the mastery of the iconic symbol system might interfere with the related cognitive processing of the actual new learning content being represented.

Research Method

General Research Question and Hypotheses

The central research question is whether training participants in the use of the iconic symbol system will have a differential impact on learning performance as measured via knowledge and application tests. Building on the theoretical base, the following hypotheses are put forward:

- Learning performance and reported cognitive load will be significantly different when learners receive a training in developing visual representations.
- Learning performance will be higher and reported cognitive load will be lower when learners are actively engaged in developing visual representations as compared to learners studying ready-made visual representation in learning materials.

Participants

The entire population of freshmen in the Pedagogical Sciences program of the faculty of Psychology and Educational sciences at Ghent University (Belgium) was involved in this study (academic year 2003-2004, N=218). The study was set up as a formal and obligatory part of the course to give the students an experiential base in view of the subsequent theoretical discussion about CTML in the course ‘Introduction to Instructional Sciences’. As to their educational background, the majority of the participants took a major in their secondary education focusing on the humanities and social sciences; a minority studied a hard sciences major. Only 5% of the target population did have prior higher education experience.

Research design

An experimental pretest-posttest research was adopted. To research the differential impact of (1) training and (2) activation, participants were assigned at random to one of the four experimental conditions: studying text only materials (T), studying text-based materials with elaborated visual representations (T+V), studying text-based materials but with the requirement to develop individual visual representations (T+D) and studying text-based learning materials and the requirement to develop individual visual representations after receiving a formal training (T+D after training). Participants worked individually and could not exchange information with other students within and/or between research conditions.

Training is the mastery of visual representations

The training presented to students in the training condition was designed on the base of Wilemans' theory (1993). In a first part the participants were introduced to his theory. Next, worked-out examples of visual representations were discussed extensively as to their relationship with the theory. Next, they were invited to develop visual representations in relation to a new text. Two participants were selected to present their visual representation on the blackboard so this could be discussed with the other participants. Immediately after the training, participants started with studying the new learning materials and taking the related pre- and posttests.

Learning materials

The learning materials consisted of three subsets. The content of the learning materials centered on the topic of 'learning styles' and was similar in the different conditions. As explained above, four different multimedia elaborations of the learning materials were developed. The visual representations embedded in the learning materials were typical for the knowledge domain as they can be found in traditional text books of this particular knowledge domain. Mayer's design recommendations were strictly taken into account (2001a, p. 191-193) to ensure the optimal design of the learning materials. When participants were invited to produce visual representation, extra space was provided in the printed materials to develop their schemas, drawings, pictures and so forth. Comparable materials were presented to the learners in the condition where participants first received a training in developing visual representations.

To test prior knowledge a pretest was presented to participants. After studying each subset, a posttest was administered. Both tests consisted of knowledge and application questions. Knowledge questions focused on remembering elements of a topic (e.g., Explain the layers in the 'onion model' of Curry?). Application questions focused on problem solving and tested the deeper understanding of the content (e.g., Explain the behavior of person X within the model of Vermunt and Vandersanden?).

Procedure

The research was set up during a single two hour session. Participants were assigned ad random, based on the alphabetical tuition list, to an experimental condition. Prior to experimentation, one group (T+D after training) received a training based on the theory of

Wileman (1993) as explained earlier. After taking the posttest of the first and the third subset of learning materials, participants were asked to estimate their perceived mental effort as a measure of cognitive load. This results in a subjective cognitive load scale (Paas, Renkl, & Sweller, 1994) in which students note the amount of effort they experienced on a scale varying from 0 (very low) to 9 (very high). Two trained, independent scorers, for whom the research conditions were masked, evaluated the answers to the open questions of the pretests and the posttests. The answers to the knowledge and application questions were scored on the base of a correction and scoring key. Test scores were standardized. Inter-rater reliability was calculated to control the quality of the scoring of 25% of the test items (Rourke, Anderson, Garrison & Archer, 2001). A person agreement of 89,7% reflects a high reliability. Data-analysis was carried out according to a pre-established procedure. Measures were compared using analysis of variance. In case of statistically significant differences, Cohen's d was calculated to determine the effect size (Talheimer & Cook, 2002).

Results

All first years students were obliged to take part in the research (N=218). Due to illness, one student did not participate in the study. 217 participants started the research; no data were lost or removed during the collection and data cleaning procedure. As a result, the full data set of 217 participants was included in the subsequent analyses.

The pretest results revealed that the prior knowledge level of all participants is very low to non-existing and as a consequence no significant differences at pretest level were detected. Table 2 presents a summary of the descriptive results. Students in the T condition, studying learning materials without visual representations, attained on average higher mean posttest scores as compared to students in other conditions. As to cognitive load, it is clear that participants studying learning materials with embedded visual representations reported the lowest level of cognitive load. In order to study the significance in differences in posttest scores, analysis of variances was carried out. This analysis was repeated in relation to the three subsets of learning materials studied by the participants in each research condition. An overview of the analysis results is presented in table 3. Significant differences in posttest results were only detected in relation to studying the first and the second subset of learning materials. No significant differences in reported mental effort were observed. Post hoc analysis of the differences in posttest scores are visualized in table 4.

In relation to the first subset of materials a significant difference is observed in the mastery of knowledge questions between the participants in the condition where learning materials are enriched with visual representations and where participants had to develop their own visual representations (T+V>T+D).Studying the results in relation to the second subset of materials, the results point at significantly higher mastery of knowledge related questions after studying learning materials without visual representations (T > T+D and T > T+D after training). When it comes to application questions, studying text with visualizations or text without visualizations seem to be more valuable (T+V > T+D after training and T > T+D after training). Looking at the overall test results (knowledge + application questions), text with visualizations result in superior performance as compared to developing visual representations after training (T+V > T+D after training). It is important to note that effect sizes of the observed significant differences are medium to large (*d* = .50 and up to *d* = .76).

Table 2. Mean scores and standard deviations for performance measures and cognitive load in the four conditions in all subsets

		Text without representations		Text with representations		Developing representations		Developing representations with training		Total score	
		M[a]	SD	M[b]	SD	M[c]	SD	M[d]	SD	M[p]	SD
Set 1	Knowledge* test	9.86	0.71	10.00	0.00	9.67	.86	10.00	0.00	9.88	.58
	Application test	5.02	4.45	5.00	4.45	5.80	4.74	6.31	4.02	5.44	4.44
	Total test score	14.88	4.67	15.00	4.45	15.47	4.90	16.31	4.02	15.32	4.55
Set 2	Knowledge test	9.86	0.62	9.57	.89	9.35	1.29	9.51	0.82	9.60	7.77
	Application test	8.43	3.47	8.45	3.30	7.85	3.98	5.67	4.40	7.77	3.86
	Total test score	18.29	3.69	18.02	3.29	17.12	4.26	15.19	4.44	17.38	4.02
Set 3	Knowledge test	9.30	1.14	9.30	1.60	8.81	1.52	9.14	1.18	9.16	1.37
	Application test	7.32	2.54	7.95	2.36	6.91	3.06	7.12	2.66	7.35	2.65
	Total test score	16.62	2.83	17.25	3.06	15.72	3.94	16.26	2.69	16.52	3.17
		M	SD	M	SD	M	SD	M	SD	M	SD
	Cognitive load 1	3.81[e]	1.46	3.26[h]	1.68	3.74[k]	1.74	3.61[m]	1.53	3.61[q]	1.60
	Cognitive load 2	4.21[f]	1.56	3.68[I]	1.72	4.34[l]	1.84	3.80[n]	1.36	4.02[r]	1.64
	Total cognitive load	8.05[g]	2.83	6.96[j]	3.21	8.07[l]	3.51	7.46[o]	2.74	7.65[s]	3.09

[a]N=70. [b]N=57. [c]N=48. [d]N =42. [e]N= 68. [f]N=67. [g]N=66. [h]N=57. [i]N=53. [j]N=53. [k]N=47. [l]N=44. [m]N=41. [n]N=40.
[o] N=39. [p]N=217. [q] N=213. [r]N=204. [s]N=202.
* Due to minimal discrimination power these tests are not included in the analyses.

Table 3. Anova-results on knowledge, application test and total score in each subset

		df	F	P	
Set 1	Knowledge	3,213	3.74	.01*	F(3,213) = 3.74, df = 3, p < .05; d = .54
	Application	3,213	1.03	.38	
	Total	3,213	.99	.40	
Set 2	Knowledge	3,213	3.02	.02*	F(3,213) = 3.02, df = 3, p < .05; d = .50
	Application	3,213	5.75	.00*	F(3,213) = 5.75, df = 3, p < .05; d = .69 F(3,213) = 5.75, df = 3, p < .05; d = .72
	Total	3,213	6.31	.00*	F(3,213) = 6.31 df = 3, p < .05; d = .76 F(3,213) = 6.31, df = 3, p < .05; d = .72
Set 3	Knowledge	3,213	1.53	.21	
	Application	3,213	1.52	.21	
	Total	3,213	2.17	.09	
		df	F	P	
	Cognitive load 1	3,209	1.36	.20	
	Cognitive load 2	3,203	1.88	.26	
	Total	3,198	1.57	.13	

Table 4. Post hoc results of the significant differences

Set 1	Knowledge	T+V>T+D	F(3,213) = 3.74, df = 3, p < .05; d = .54
	Application	NS	
	Total	NS	
Set 2	Knowledge	T > T+D	F(3,213) = 3.02, df = 3, p < .05; d = .50
	Application	T > T+D after training	F(3,213) = 5.75, df = 3, p < .05; d = .69
		T+V > T+D after training	F(3,213) = 5.75, df = 3, p < .05; d = .72
	Total	T > T+D after training	F(3,213) =6.31 df = 3, p < .05; d = .76
		T+V > T+D after training	F(3,213) = 6.31, df = 3, p < .05; d = .72
Set 3	Knowledge	NS	
	Application	NS	
	Total	NS	
	Cognitive load 1	NS	
	Cognitive load 2	NS	
	Total cognitive load	NS	

Considering the cognitive load measures, the descriptives suggest that participants studying learning materials with embedded visual representations reported the lowest levels of cognitive load. The highest levels of cognitive load were reported when studying textual learning materials without visual representations. But, the analysis of variance results make clear that none of these differences are significant.

Discussion

The first hypothesis tested the differential impact of the training related to visual representations. The descriptive results and analysis of variance results clearly show that there is no positive influence of training. Although training has proven its value in researches relating to knowledge maps (Chmielewski & Dansereau, 1998; Novak, 2005; Robins & Mayer, 1993), other researches come to less positive findings (Bahr & Dansereau, 2005; Bowen & Roth, 2003; Roth & Bowen, 2003; Roth, Bowen, & Masciotra; 2002). Some authors state that takes more time and students need to get more experienced in a knowledge domain before a sufficient mastery level of an iconic symbol system will result in consequent better learning performance (Dori & Belcher, 2005; Gilbert, 2005). Also Airey & Linder (2007) point out that developing mastery of the underlying 'language' of representations takes time and therefore criticize a large number of short term CTML-studies. The results of the present study could also be studied from the perspective of the alternative hypothesis put forward earlier in this article. Training imposes extra work load and interferes with the cognitive processing of the new learning content. This reduces the available capacity of working memory to develop integrated schema and the resulting learning performance. The results suggest that this alternative hypothesis might be valid. Participants in the training condition (T+D after training) experience a higher level of cognitive load as compared to participants studying textual materials with embedded and ready-made visual illustrations (T+V); though these differences are not significantly different. This nevertheless relates with earlier research findings stating that active learning theory can lead to higher performances when the cognitive system is not overloaded (Robins & Mayer, 1993).

The second hypothesis, focusing on the positive differential impact of activation by asking participants to develop individually their visual representations, is also not confirmed. The performance of participants studying learning materials enriched with ready made visual representations was significantly higher as compared to students that were invited to develop their own visual representations. The results corroborate results of the initial CTML-studies. The analysis of the cognitive load suggests that also in view of the second hypothesis, the alternative hypothesis might be valid. Asking students to develop their visual representations, interferes negatively with the actual processing of the new complex learning content and invokes extraneous cognitive load.

In general, the findings of the present study can be linked to a number of other studies. Cox (1999), for example, states that the impact of graphical versus textual representations might be affected by the degree to which learners understand the semantics of iconic symbol systems. The semantics of iconic symbol systems might be initially complex to understand. This is suggested by Lowe (2003), who states that subjects extract information easier from signs that reflect clear visual-spatial characteristics, such as structural coherence and distinctive appearance (e.g., closely related to reality). This can also be derived from the findings of Dobson (1999) who found that the impact of representations is influenced by the difficulties learners have to interpret the diagrams. He determined that students actually prefer lexical parts in learning materials as compared to diagram-representations. This brings us back to the importance of prior knowledge, implying mastery of both knowledge domain content (concepts, facts, procedures, …) and the related iconic symbol systems (Seufert,2003). This was already suggested by Scaife and Rogers (1996) and Postigo and Pozo (2004) when they state that novices lack the necessary knowledge about cognitive structures and processes to develop a full understanding of learning processes related to visual representations.

Limitations and conclusions

The present study and results can be criticized from a number of perspectives. First, the nature and quality of the visual representations presented in the learning materials (T + V condition) can be questioned. But, both the content and the visual representations used, were very similar to those presented and incorporated in text books and other learning materials in the particular knowledge domain. In addition, the visual representation were screened by experts and considered to be in line with CTML-guidelines. Secondly, the fact that the study was set up with novices might have been a handicapping factor. Literature pays a lot of attention to the difference between experts and novices (Airey & Linder, 2007; Anderson & Leinhardt, 2002; Kulhavy & Stock, 1996). In addition, Airey and Linder (2007) point out that learners, when developing visual representation, might make wrong choices since they are insufficiently acquainted with adequate ways to develop representations. Though the participants in the present study were first year students in the field of educational sciences their understanding and mastery of the underlying iconic symbol system might still have been too weak; even when training was provided. Thirdly, as already suggested above, the duration of the present studies and certainly of the training might have been too short. Though the present studies lasted longer than earlier CTML-studies, our assumptions about the mastery of an iconic symbol system might have neglected the need to apply a larger time frame. Fourthly, relating to training a few remarks can be made. It can be argued that not only external factors play a role in training. Nijman (2004) state that also specific internal trainee characteristics affect the general performance. It is even stated that trainee characteristics account for most of the variability in training transfer scores. Maybe more attention should be paid to these characteristics. A last limitation is related to the particular knowledge domain studied in this research. The choice for the particular knowledge domain was inspired by earlier research that pointed at conflicting outcomes when studying the standard list of CTML-guidelines (De Westelinck, et. al., 2005; Dobson, 1995, 1999; Lowe, 2003). Nevertheless, contrasting different knowledge domains might help to come to a better understanding of the role of mastery of the underlying iconic symbol system and the expected impact of training.

This list of limitations of the present study put forward a clear agenda for future research: involve novices and experts, set up studies in a larger time frame to allow a more grounded development of the underlying iconic symbol systems and this in a variety of knowledge domains. This is a challenging agenda for instructional designers since it turns attention away from simple outcomes related studies to studies that centre on mediating internal variables and processes and conditions that interact with cognitive processing of multimedia learning materials.

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Chapter 7
General discussion and conclusion

The research presented in this dissertation focuses on the impact of the Cognitive Theory of Multimedia Learning (CTML) (Mayer 2001a, 2001b, 2003, 2005). The theory formulates 'principles' to design multimedia learning materials which lead, according tot Mayer (2001a, 2001b, 2003, 2005), to higher learning performances compared to performances achieved when learning materials without multimedia elaboration. As stated in the introductory chapter, the term 'guidelines' is used throughout the dissertation when referring to the principles of Mayer.

While Mayer concentrated on knowledge domains in the natural sciences questions were raised if and under what circumstances these guidelines would also lead towards higher performances when learners study multimedia learning materials compared to students studying learning materials that are not multimedia elaborated. As replicating research did not show the same promising results as the CTML-research in the natural sciences the researchers were obliged to look into new concepts that could lead towards new and additional guidelines.

In this chapter an integrated overview of the results of the different studies is presented. First, the theoretical background of CTML will be summarized. Next the specific researches used in the present dissertation will be discussed, starting with replication research of original CTML-studies, followed by studies in which variables and/or guidelines have been added such as activation, collaboration, and training. Also the cognitive load assessment will be tackled in this discussion. In a next step, the general research question and the five research questions (in total six research questions) that have been presented in the introduction of this dissertation will be discussed. The results reported in the different chapters are outlined and related to one another. Finally, we conclude with a number of limitations of the current studies, directions for future research, and implications of the research.

Theoretical base of and educational practice related to the Cognitive Theory of Multimedia Learning

The rise of multimedia learning materials is a logical result of the increasing adoption of information and communication technologies (ICT) in education. ICT has provided instructional designers with new teaching and learning techniques leading to enriched multimedia learning materials. In this visual culture visual literacy is a skill with growing importance. Wileman (1999) defined this as "the ability to read, interpret and understand information presented in pictorial or graphic images" (Wileman, 1999, p. 114). In other words learners need to master this skill/compentence to read, understand and comprehend these signs. In this context the concept of iconic symbol signs is introduced. These signs comprise a wide variety of visual representations that differ in the way they are strongly, weakly and sometimes even not based on realistic representations. The empirical evidence underpinning the educational potential of iconic symbol signs has influenced educators and instructional designers to integrate multimedia materials into learning materials (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Mayer, 2001a, 2003, 2005; Novak, 1998; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schnotz, 2002; Schwan & Riempp, 2004). To support learning performance from learning materials enriched with iconic symbol signs, learners need to be competent in reading, understanding and applying those signs and symbol systems (Ainsworth & Loizou, 2003; Angeli & Valanides, 2004; Chandler, 2004; Chang, Sung, & Chen, 2002; Lewalter, 2003; Lowe, 2003; Mayer, 2001a, 2003, 2005; Novak, 1998; Rouet, Levonen, & Biardeau, 2001; Roth & Bowen, 1999; Roth, Pozzer-Ardenghi, & Han, 2005; Schnotz, 2002; Schwan & Riempp, 2004). In the introductory chapter the distinction between depictive and descriptive representation was discussed. While realistic descriptive representations are easily understandable and comprehended, other types of representations such as icons and other similar signs require more time and practice for learners to understand and use them correctly. Although much research has been carried out that supports enriching learning materials with multimedia building on iconic symbol systems (Mayer, 1989, 2001, 2002, 2003; Mayer & Anderson, 1991, 1992; Mayer & Moreno, 1998; Mayer & Simms, 1994; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995), there are also studies that question the theoretical assumptions and consequently its straightforward application in all knowledge domains (Brünken, Plass, & Leutner, 2004; Cox, 1999; Dobson, 1999; Dutke & Rinck, 2006; Goolkasian, 2000; Guttormsen Schär & Kaiser, 2006; Guttormsen Schär & Zimmerman, 2006; Huk, 2006; Lowe, 2003; Moreno & Durán, 2004; Postigo & Pozo, 2004; Prangsma, in press; Scaife & Rogers, 1996; Schnotz & Bannert, 2003). This dissertation fits into the latter research strand that asks for more empirical evidence to ground CTML into a larger variety of knowledge domains. Consequently, these studies put forward alternative and additional guidelines to the CTML.

As the CTML was studied, questions were raised concerning the generalizibilty of the research conclusions. The first study was set up to check whether a straightforward application of the CTML-guidelines could be pursued. A clear answer was not provided by this replication research as it showed inconsistencies with the CTML-findings. This led to studies that included also other knowledge domains. After the introduction of the knowledge domains the question was raised whether other educational theoretical concepts such as activation, collaboration and training, could present adequate extensions of the CTML-guidelines as stated by Mayer (2001a).

In all of the studies presented in this dissertation, a comparable experimental design was adopted. The subsequent studies have been set up as steps in a design-based research cycle. Clearly, the presented studies took the design-based research cycle into account by enclosing the findings of earlier studies, repeating earlier features, adding new alternative interventions, and partly replicating such earlier findings. To start with, the CTML-guidelines were researched in a replicating study in the social sciences. As the results of that research was not what was expected it made us revert to the literature and search for new and additional guidelines. The adoption of additional guidelines (i.e., activation, collaboration, training) is an example of how new instructional approaches were considered in the subsequent studies. The subsequent studies share a number of features that enable us to develop a consistent empirical body of knowledge about the impact of the original CTML and alternative guidelines. First, the different studies were set up in the same context of a university course for university freshman. All the studies were set up in a naturalistic quasi-experimental setting during three consecutive academic years. Each study started with an overall prior knowledge test about the content of the learning materials to be studied. Additional information about background variables of the participants was obtained. Research participants were randomly assigned to specific experimental or control condition. Prior to their admission to university, nearly 95% of the research participants finished General Secondary Education, but by taking different majors. Based on the 2006 analysis of the typical student population in this faculty, we can state that 50% took a major in humanities, 20% graduated with a major in social sciences, and 30% majored in hard sciences. Finally, 5% of the research participants had already obtained a bachelor degree. In each research condition, participants studied subsequent sets of learning materials (three to four sets). Each set started and ended with the administration of a knowledge and application test. Knowledge tests studied the retention of information by learners; application tests went a step further by testing how much of the knowledge the learners could transfer or apply in similar situations. Twice during the study of the sets of learning materials, participants were asked to score their perceived cognitive load. In the literature, measurement of cognitive load is mainly based on the learners' subjective report of their perceived mental effort. This results in a subjective cognitive load score. The scale applied in these studies was developed by Paas, Renkl, and Sweller (1994). Participants write down the amount of effort they needed to study the materials on a scale varying from 0 to 9. Use of this type of scale is reported to have a high reliability (Cronbach's α) of .90 to .82 (Paas, 1992, Paas et al., 1994). Building on the particular guidelines, the multimedia elaboration, and the way learner(s) processed the learning materials enriched with the multimedia representations, varied in the experimental conditions of each separate study.

Overview of the research questions and summary of the results

Building on the theoretical background explained in previous chapters, and in the introduction, five research studies were conducted. The general research question, referred to as research question 1, can be formulated as: Can we generalize the design guidelines for designing learning materials derived from the Cognitive Theory of Multimedia Learning which have been gathered primarily from the natural sciences to other domains of learning? This is stated as the first research question. From this general question, five central research questions can be formulated:

- Do multimedia learning materials in the domain of the social sciences result in higher performances of participants on knowledge and application tests and lower levels of perceived cognitive load compared to participants who have not been offered multimedia learning materials? We refer to this as research question 2.

- To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load, influenced by the mastery level of the used iconic symbol systems? We refer to this as research question 3.
- To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load influenced by active engagement in the learning process? We refer to this as research question 4.
- To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load in a collaborative setting influenced by active engagement? We refer to this as research question 5.
- What is the impact of training on the performance of participants on knowledge and application tests and the levels of perceived cognitive load? We refer to this a research question 6.

In the next section, the results of the studies set up to research these questions are brought together and interlinked. First the five last research questions will be discussed as they are be necessary to answer the general first research question.

Research questions

Research question 2: Do multimedia learning materials in the knowledge domain of the social sciences, result in higher performances of participants on knowledge and application tests and lower levels of perceived cognitive load compared to participants who have not been offered multimedia learning materials?

The purpose of the research in chapter two was to replicate traditional CTML-studies and to test whether the CTML-guidelines are applicable in the knowledge domain of the social sciences. An experimental research programme involving 190 freshmen, enrolled in the Pedagogical Sciences programme of the faculty of Psychology and Educational Sciences at Ghent University (Belgium) and assigned randomly to research conditions, was carried out. Nine themes concerning concepts in the educational sciences were presented to the learners.

The results did not present an unequivocal answer to the research question (Table 3 on p. 48) although some sub studies showed clearly significant results different from those found in traditional CTML-research. The fact that the results do not unequivocally confirm the CTML-guidelines led to the conclusion that the CTML-guidelines cannot be generalized in a straightforward way to another knowledge domain.

Research question 3: To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load influenced by the mastery level of the used iconic symbol systems?

Chapter three built on theoretical and empirical evidence about the need to master the iconic symbol used to develop a multimedia representation. The study was set up in a variety of knowledge domains that helped to determine whether acquaintance with the iconic symbol system influences performance of participants in knowledge domains where different types of iconic symbol systems are being used: natural science and educational science. In each of these knowledge domains learning materials were developed using two multimedia elaborations: text and visual representations (T+V) and visual representations and audio (V+A) and one condition without multimedia elaboration: text only (T). In this research 286 students, freshmen enrolled in the Pedagogical Sciences programme of the faculty of Psychology and Educational Sciences at Ghent University (Belgium), participated in the research. The potential differential impact of familiarity with an iconic symbol system in different knowledge domains became evident in the results. Participants studying learning materials from the – for them - more familiar educational sciences, obtained significantly higher post test scores in most sets of learning materials (Table 8, p. 70). These results support our hypothesis and are in line with findings of other studies (Bowen & Roth, 2002, 2003; Roth & Bowen, 2003; Roth, Bowen, & Masciotra, 2002).

Though the results were promising, some inconsistencies were observed. Explanations have been put forward to explain this. For instance, the high complexity level of the learning materials in one of the subsets, studied in detail after the experiment was carried out, could be an explanatory factor (Table 4, p. 65). An analysis of the cognitive load reported by the participants shows a clear trend. The cognitive load is higher when studying learning materials from the natural sciences though differences are not significant (Table 6, p. 69). The results nevertheless helped to lead to the tentative conclusion that the learners' familiarity with, or his/her mastery level of, the iconic symbol signs and systems can influence learning performance. Though the results helped partly to underpin the hypotheses, more research was needed.

Research question 4: To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load influenced by active engagement in the learning process?

Because the previous chapters provided evidence that the generalizability of the CTML-guidelines to other knowledge domains is questionable and that the mastery level of the iconic symbol system could be an influencing factor, it was suggested that other educational conceptions could help to develop additional guidelines that foster learning performance of learners when studying multimedia learning materials. In a study, the entire population of freshmen enrolled in the Pedagogical Sciences programme of the faculty of Psychology and Educational Sciences at Ghent University (Belgium) participated in the resulting study (N=219). An experimental design was adopted, based on random assignment of participants to different research conditions. Building on a variety of activation levels, four research conditions were developed. In each of the research conditions, participants studied an alternative multimedia elaboration of the same set of learning materials (i.e., text and ready-made visual representations (T+V), text and pre-worked examples of visual representations (T+PW) and text and the invitation to develop visual representations (T+D) and a condition without multimedia elaboration (i.e., text only; T). The manipulation of the levels of activation was labeled the ‘activation guideline’. The learning materials in each of the four conditions consisted of four themes related to new, but complex theoretical constructs in the field of the educational sciences.

The results show a clear relationship between the level of activation in developing visual representations, the level of performance, and the level of perceived cognitive load. The highest level of active involvement led to the highest learning performance and invoked the lowest level of cognitive load. The positive impact is in line with the meta-analysis results as reported by Marzano, Pickering, and Pollock (2001) when discussing the active development of non-linguistic representations. More recent studies also confirm the findings that learner-generated drawing is a strategy that improves learning from text-only materials (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Lowe, 2003; Moreno & Valdez, 2005; Schnotz & Rasch, 2005; Stern, Aprea, & Ebner, 2003; Van Meter, Aleksic, Schwartz, & Garner, 2006; Yoder & Hochevar, 2005). As a result, the conclusion may be drawn that the activation guideline enriches the potential of the available CTML-guidelines.

Research question 5: To what extent is the learning performance of participants on knowledge and application tests and the levels of perceived cognitive load in a collaborative setting influenced by active engagement?

Chapter five replicated the previous study, but added a collaborative dimension to the guidelines. Participants involved in the study were enrolled as freshmen in the Pedagogical Sciences program of the faculty of Psychology and Educational sciences of Ghent University (Belgium). The entire population participated in the study (N=217) as participation was a formal part of the course ‘Instructional Sciences’. Participants were assigned randomly to experimental conditions.

To investigate whether collaboration has a positive influence on performance and reduces cognitive load, four different conditions were introduced in an experimental research design. In each of these conditions learning materials were presented with varying types of multimedia elaborations: text and visual representations (T+V), text and development of visual representations (T+D) and text and development of visual representations after training (T+D after training) and a condition where learning materials were not multimedia elaborated: text only (T). In each of the four conditions, participants worked together in small groups during the ‘study’ phase; but not during the test phase. Again, the four conditions reflected a progression in active engagement as they evolved from no activation to high activation of the groups of learners. In the condition text only (T), learners received learning materials consisting solely of the body of text (i.e., without visual representations). Learners in the condition T+V studied learning materials consisting of text enriched with visual representations. These visual elements were developed according to the CTML-guidelines. The condition T+D invited learners to develop their own visual representations. This was also the case in the last condition (T+D after training) where the learners were invited to develop their own visual representations but received in advance specific training about iconic symbol systems to represent knowledge elements.

There is theoretical and empirical evidence to ground the assumption that collaboration can result in higher learning performance. Unexpectedly, the condition where text was enriched with visual representations led to the highest posttest performance, resulting in the rejection of our hypothesis. Also other researchers arrived at these types of conflicting results (see e.g., Prangsma, 2007; in press). Several plausible explanations can be adduced to explain such conflicting findings. Individual differences, argued by Suthers and Hundhausen (2003) could have played a mediating role during collaboration. Also group composition may have been an contributing factor in influencing the nature of the collaboration (Kichin & Hay, 2004). ‘Overwhelming’ and ‘underwhelming’, concepts introduced by Lowe (2004) could have played a role in this context. The first is thought to arise if presentational characteristics of the signs are such that the learner is unable to process the available information effectively under the prevailing conditions. There is a mismatch between the way in which the iconic symbol signs deliver information on one hand, and the learner's capacity to process it effectively on the other. Underwhelming can be thought of as the converse of overwhelming: the signs lead to the learner being insufficiently engaged so that the available information is under-processed. Because signs can provide a direct depiction of the changes involved in a dynamic system, learners need do no more than observe these dynamics as they are portrayed. There is no need to carry out the intensive mental manipulations required for a static depiction of the same situation. To conclude, the collaborative guideline was not a successful additional guideline to foster learning performance when studying multimedia learning materials.

Despite these results, some promising aspects were noted in relation to cognitive load. Participants in the condition where active engagement was requested consequently report lower levels of cognitive load. This is in line with results reported in other researches (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; van Meter, Aleksic, Schwartz, & Garner, 2006; Yoder & Hochevar, 2005).

Research question 6: What is the impact of training on the performance of participants on knowledge and application tests and the levels of perceived cognitive load?

The entire population of freshmen enrolled in the Pedagogical Sciences programme of the faculty of Psychology and Educational sciences at Ghent University (Belgium) was involved in this study (academic year 2003-2004, N=218). The study was set up as a formal and obligatory part of the course to give students an experiential base in view of the subsequent theoretical discussion about CTML in the course ‘Introduction to Instructional Sciences’. To research the differential impact of (1) the training guideline and (2) the activation guideline, participants were randomly assigned to one of the four experimental conditions: studying text only materials (T), studying text-based materials with elaborated visual representations (T+V), studying text-based materials but with the requirement to develop individual visual representations (T+D) and studying text-based learning materials and the requirement to develop individual visual representations after receiving a formal training (T+D after training). Participants worked individually and could not exchange information with other students during and between research conditions.

The first hypothesis tried to answer the question whether the training guideline could be seen as an additional guideline leading towards a differential impact on learning performances. The results clearly demonstrate that there is no positive influence of training in the use of iconic symbol systems to work with multimedia representations. Although training has proven its value in research on mind maps / knowledge maps (Chmielewski & Dansereau, 1998; Novak, 2005; Robins & Mayer, 1993), other research has shown less positive findings (Bahr & Dansereau, 2005; Bowen & Roth, 2003; Roth & Bowen, 2003; Roth, Bowen, & Masciotra; 2002). Some authors state that it takes more time to process learning content and students need to get more experienced in a knowledge domain before sufficient mastery of an iconic symbol system will result in higher learning performance (Dori & Belcher, 2005; Gilbert, 2005). Also Airey and Linder (2007) point out that developing mastery of the underlying 'language' of representations takes time and consequently, criticize the short-term nature of a large number of short-term CTML-studies. The results of the present study could also be studied from the perspective of the alternative hypothesis put forward: training imposes extra work load and interferes with the actual cognitive processing of the new learning content. This reduces the available capacity of working memory for developing integrated schema and the resulting learning performance. The results show differences in the direction of the alternative hypothesis, although these differences are not significant. This nevertheless is related to earlier research findings stating that activation can lead to higher performances unless the cognitive system is not overloaded (Robins & Mayer, 1993).

The second hypothesis, focusing on the differential impact of the activation guideline by asking participants to individually develop their visual representations, is also not confirmed. The performance of participants studying learning materials enriched with ready made visual representations was significantly higher as compared to that of students that were invited to develop their own visual representations. The results corroborated the results of the initial CTML-studies. The analysis of the cognitive load suggests that, also given the second hypothesis, the alternative hypothesis might be valid. Asking students to develop their visual representations negatively interferes with the actual processing of the new complex learning content and evokes extraneous cognitive load.

In general, the findings can be linked to a number of other studies. Cox (1999), for example, states that the impact of graphical versus textual representations might be affected by the degree to which learners understand the semantics of iconic symbol systems. The semantics of iconic symbol systems might be initially too complex to understand. This is also suggested by Lowe (2003) who states that subjects extract information easier from signs that reflect clear visual-spatial characteristics, such as structural coherence and distinctive appearance (e.g., closely related to reality). This can further be derived from the findings of Dobson (1999), who found that the impact of representations is influenced by the difficulties learners experience in interpreting the diagrams. He for example, determined that students actually prefer lexical parts in learning materials as compared to diagram-representations. This brings us back to the importance of prior knowledge, implying mastery of both knowledge domain content (i.e., concepts, facts, procedures, …) and the related iconic symbol systems (Seufert, 2003). This was already suggested when it was stated that novices lack the necessary knowledge about cognitive structures and processes to develop a full understanding of learning processes related to iconic symbol signs (Postigo, & Pozo, 2004; Scaife, & Rogers, 1996).

Building on the results and the discussion, it is now possible to answer the general research question which was: Can we generalize the design guidelines for designing learning materials derived from the Cognitive Theory of Multimedia Learning which have been gathered primarily from the natural sciences to other domains of learning? If the conclusions from the previous chapters are taken into consideration, the question cannot be answered unequivocally. We found for example that the efficacy of the CTML-guidelines might be marred by the mediating impact of the mastery level of the iconic symbol system commonly adopted in a particular knowledge domain. Straightforward application of the CTML-guidelines does not lead in every knowledge domain to higher learning performances. Building on this intermediate conclusion, the question was raised as to whether other educational conceptions can enrich the CTML and expand the number of CTML-guidelines. Activation, collaboration and training were then included. Some results of these studies reflect inconsistencies. Research provided evidence that ‘activation’ in the use of iconic representations could lead to higher performance. But this was partly contradicted by results of other studies; especially when combined with collaboration.

Promising results are observed relating to the impact on cognitive load. Learners reported lower levels of cognitive load when they were activated, and in knowledge domains they were acquainted with and when they were activated in a collaborative setting. Surprisingly the cognitive load was higher when the learners had received training. These inconsistent results plead for more and further research concerning this topic.

Limitations and directions for future research

In this section, we present a series of limitations of the studies reported in this dissertation. Moreover, some directions for future research are presented to corroborate the research findings or to study new research questions that arise from the findings.

A first limitation is that the studies were carried out with students in the educational sciences as research population. This helped to control for bias resulting from variation in the target audience, but future research needs to be set up in other contexts to generalize the present research results to different knowledge domains and different student populations. The need for involving students studying other knowledge domains is also necessary to be able to present conclusions that can be generalized to the entire domain of the social sciences.

Secondly, we were unable to compare different age groups or educational levels since the studies were all conducted with the participation of university freshmen. It is considered crucial to involve more advanced-level students in different knowledge domains. This will allow researchers to study the impact of the mastery level of the iconic symbol systems used to develop multimedia representations in more complex and advanced knowledge domains.

A third limitation concerns the way we studied the hypothesis about the critical role of the mastery of the iconic symbol system. In the current studies, the same group of participants was presented with learning materials and related iconic symbol systems of two knowledge domains. Future studies could involve students from different knowledge domains, studying learning materials from different knowledge domains (e.g., social science students and content versus engineering study students and content). An attempt was made to set up this kind of study, but this failed due to practical reasons beyond the control of researchers.

Fourthly, research involving larger samples is a necessity to be able to apply more advance analysis techniques and to be able to study the 'power' of the statistical results.

The fifth limitation is related to individual variables in students, such as their learning styles, study approach, prior educational background and pacing. These variables could have played a role or could have interacted with the independent variables and/or processes pursued during the studies. Since our research sample was rather homogeneous in terms of prior knowledge, the role of prior knowledge was hardly of significance. Nevertheless, future research should consider Mayer's (2001a) seventh guideline that stresses the critical role of individual differences in for example, prior knowledge and preferences in the representation of learning materials. Research by, for instance, Cox reveals that "there are large variations between subjects in the types and modalities of external graphical representations that they use in their solutions" (1999, p. 356). He also concludes that iconic symbol systems might serve different cognitive functions for different subjects. When studying the differential impact of individual differences, the adoption of other statistical analysis techniques should be considered when the design allows it. Structural Equation Modelling (SEM) can for instance be adopted to test the impact of mediating variables and co-variables.

Questions can be raised about the quality of the multimedia representations that may be adduced as a sixth limitation. Do the results rather reflect the influence of less effective elaboration of for example, visual representations? This is important since recent studies (see e.g., Schnotz & Bannert, 2003) give support to the assumption that non task-appropriate representations do not foster comprehension and mental model construction. As explained, much time and effort was invested in the design of the representations by a team of designers. The representations were moreover typical of the approach found in textbooks in the field of educational sciences or natural sciences.

A seventh limitation deals with the selection and complexity level of the specific learning content. This was an issue of particular importance when designing the present studies. The researchers did build on about five years of experience in developing learning materials for courses for this group of freshmen. In addition, the complexity level of the learning materials was scrutinized. Preferably, this should have been better this was done prior to the research with an objective measure and would have influenced a better selection of the learning content. The results point clearly at a possible side-effect of content complexity. Content complexity should be subject of more CTML-oriented research.

The eighth limitation is related to the duration of the studies. The original CTML-studies of Mayer and his colleagues were very limited in time. In the present studies, larger chunks of learning materials had to be processed during a longer period of time. It is possible that more demanding study tasks result in divergent research results compared to Mayer's original studies. Also Tabbers, Martens and Van Merriënboer (2004) mention this particular divergence between the results of their studies and those of Mayer. Task duration might be a source of ambiguous research results.

The ninth and last limitation is related to the timing of the posttest, administered immediately after studying the learning materials. In future research, a delayed impact of the alternative multimedia presentations could be taken into consideration. A recent study found that posttest results differed when focusing on immediate posttest results and long-term posttest scores (Atkinson, Clark, Harrison, Koenig, & Ramirez, 2007). This is particularly true when we expect an impact of training on the development of or the interpretation of iconic symbol systems and iconic symbol signs. In the present studies, we took the prior knowledge of the participants of the learning content into account. It would have been – additionally – important to determine prior knowledge (i.e., level of mastery) of the use of the iconic symbol system in a certain knowledge domain, and to include data about this mastery in the analysis of the results.

Building on our results and limitations, additional directions for future research can be presented. Focusing on being and/or becoming familiar with an iconic symbol system, future studies could center on the characteristics of instructional processes focusing on getting acquainted with the iconic symbol system as an integrated part of studying in a knowledge domain. In addition, a more active learner role could be studied, for example, by asking learners to develop their own multimedia representations and/or to build on available personal iconic symbol systems. This could be the start of a qualitative way to look into the CTML-studies.

Implications

The research presented in this dissertation not only helps develop a better insight in the impact of the Cognitive Theory of Multimedia Learning, but also provides insights with direct and clear implications for educational practice. In this section, the most important practical implications of the results will be outlined.

Even though it is not yet completely clear if and how the CTML-guidelines influence learning performances in different knowledge domains, educational designers should become aware of use of the differential impact of the guidelines on learning. The results especially urge designers to be aware of the nature of the iconic symbol systems they apply when developing learning materials. They should consider this in view of characteristics of the learner (e.g., novices) and whether they are acquainted with the iconic symbol system or not. Questions should be asked about the relationship between the representation and the textual content, about the level of comprehension needed to interpret the representation in an adequate way, and so forth.

The CTML builds on the assumption that learning takes place via two parallel channels (i.e., dual channel assumption). As both the visual and the auditory channel have a limited capacity it is most helpful for learners to exploit both channels while studying. The current research results make clear that visual representations and audio support do not always result in higher performance. Visual representations can lead to an increased cognitive load that, in its turn, can lead towards extraneous working memory. And this can result in lower performances. This implies that instructional designers should be careful in their designing and development of multimedia learning materials. Our results clearly show that to a certain extent learners are mostly used to studying textual information, or text enriched with iconic symbol signs and not audio.

Educational designers should also pay attention to a sufficient level of learner activation when designing multimedia learning materials. Learners are likely to attain a higher level of learning performance and experience a lower level of cognitive load when they are more actively engaged in the learning process. Active engagement by developing personal iconic symbol signs might also be beneficial, but this has to be carefully balanced with time management. This was also suggested by Moreno and Valdez (2005) and Tabbers, Martens and Van Merriënboer (2003) who refer to a lack of time control by participants who are actively engaged in designing representations. This is not an easy task for instructional designers. Nonetheless, they should try to include activation in learning materials and/or to provide alternative elaborations for specific students.

The same implication can be made in relation to collaboration. Earlier research is very consistent in stating that collaboration is helpful for learners to understand and comprehend learning content. Designers could extend the potential of collaborative learning to the design of learning materials that invite learners to work together and to discuss the content and multimedia elaboration of such learning material.

A key implication of the research findings is that the iconic symbol systems that are being used to develop multimedia learning materials ought to receive more attention during the learning material design process and teaching practice. Novices are not always able to grasp, understand and comprehend the iconic symbol systems in a particular knowledge domain. However, only through exercise and practice will learners reach the mastery level discussed in the first chapter. If there is neither time nor place to practise this, learners will find themseleves hard pressed to reach a sufficient mastery level and will experience difficulties in gaining an understanding of the representations in the particular knowledge domain.

To conclude

The research presented in this dissertation aimed at gaining an understanding how the CTML-guidelines work in different knowledge domains and how activation, collaboration and training could be relevant conceptions to expand CTML. The general research question embodied the idea that educational scientists should reflect upon the CTML in general. Guidelines are not standard recipes wherewith to answer all questions and solve all problems. Future research should question available and alternative guidelines that are grounded in a clear theoretical base. We nevertheless hope that the present dissertation has proved a valuable first attempt in this direction that could result in more effective, efficient and satisfying multimedia learning materials.

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Nederlandstalige samenvatting

(Summary in Dutch)

Veralgemeenbaarheid van de designprincipes voor leermaterialen volgens de “Cognitieve Multimedia Theorie”.

Het onderzoek dat wordt voorgesteld in dit proefschrift, focust op de studie van de impact van ontwerp- en ontwikkelrichtlijnen die zijn afgeleid van de Cognitieve Theorie van Multimedia Leren (CTML). Op basis van de CTML zoeken veel onderzoekers naar effectieve ontwerprichtlijnen om leermaterialen te ontwikkelen die leiden tot betere leerresultaten van lerenden. Dit proefschrift sluit aan op deze zoektocht. Daarbij wordt de validiteit onderzocht van de CTML en de ervan afgeleide ontwerprichtlijnen in kennisdomeinen die verschillen van deze waarin de theorie aanvankelijk werd ontwikkeld. Ten tweede staat het concipiëren en evalueren van een aantal aanvullende richtlijnen centraal in dit proefschrift.

De Cognitive Theory of Multimedia Learning

In het eerste hoofdstuk van het proefschrift wordt een overzicht van de verschillende theorieën die het gebruik van multimedia in leermaterialen richting kunnen geven. Door de algemene toename van het gebruik van informatie- en communicatietechnologie (ICT) in vele leer- en onderwijscontexten wordt namelijk meer en meer gebruik gemaakt van multimedia bij het ontwerp en ontwikkelproces. Daardoor worden leermaterialen steeds vaker verrijkt met representaties die voortbouwen op specifieke ‘iconic symbol signs’ of een ‘iconic symbol system’ die het de lerende eenvoudiger moet maken. ‘Iconic symbol signs’ wordt gebruikt om alle externe grafische representaties onder welke vorm dan ook aan te duiden. De CTML is gekozen als de basistheorie om te beschrijven en te verklaren hoe lerenden voordeel hebben bij het bestuderen van multimedia leermateriaal. De CTML is gebaseerd op het informatieverwerkend model van menselijk leren. Op basis van de CTML zijn door de oorspronkelijke en latere onderzoekers ontwerprichtlijnen afgelijnd. De multimedia-richtlijn stelt dat lerenden beter presteren wanneer tekst verrijkt is met beeldmateriaal dan wanneer enkel tekst wordt bestudeerd. Volgens de ‘spatial contiguity’-richtlijn is het leereffect groter wanneer de tekst en het beeldmateriaal dichtbij elkaar geplaatst worden in ruimte. De ‘temporal contiguity’-richtlijn is hiermee vergelijkbaar, maar heeft het dan over het samen aanbieden van audio en tekst i.p.v. de audio aan te bieden na het lezen van de tekst. De coherentie-richtlijn stelt dat lerenden beter leren wanneer alle overbodig materiaal, tekst en woorden, verwijderd worden uit het leermateriaal. De modaliteitsrichtlijn stelt dat het verrijken van beeldmateriaal met audio beter werkt dan het verrijken van beeldmateriaal met tekst. De redundantie-richtlijn stelt dat het toevoegen van gedrukte woorden niet leidt tot betere leerresultaten wanneer er al beeldmateriaal en gesproken woorden aangeboden werden. Een laatste richtlijn benadrukt individuele verschillen in de effectiviteit van de vorige richtlijnen. Ze zijn effectiever bij lerenden met weinig voorkennis en met een goed ontwikkeld ruimtelijk voorstellingsvermogen.

De effectiviteit van de CTML-richtlijnen is door de ontwikkelaars ervan (zie Mayer en collega's) empirisch onderbouwd. Op theoretisch vlak verklaren ze de effectiviteit door te verwijzen naar een tweetal theoretische mechanismen: de dual-channel assumptie en cognitive load. De dual-channel assumptie ondersteunt rechtstreeks het gebruik van multimedia (bijv. het gebruik van geluid naast tekst) omdat gesteld wordt dat lerenden informatie kunnen verwerken via twee parallelle kanalen: een visueel kanaal (voor bijv. tekst) en een auditief kanaal (voor bijv. een commentaarstem). Het inspelen op beide kanalen bij het ontwerpen van leermaterialen ondersteunt daarom de meer efficiënte verwerking van de informatie in de leermaterialen. Inherent aan de CTML is ten tweede de notie van cognitive load/cognitieve belasting. Het beter verzorgen van de presentatie van de leermaterialen wordt veronderstelt de extraneous cognitive load te verminderen waardoor de verwerking van de kennis in het werkgeheugen wordt bevorderd en de ontwikkeling van mentale schema's en/of de retrieval ervan wordt bevorderd.

Basisassumpties bij de CTML

De CTML bouwt verder op een basisassumptie, die in de theorie zelf niet is geëxpliciteerd. Een conditie is namelijk dat bij het ontwerpen van multimedia en dus bij het toevoegen van representaties aan tekstuele leermaterialen de lerenden de gebruikte 'iconic symbol signs' begrijpen. Het is een voorwaarde dat de lerenden het gehanteerde 'iconic symbol system' voldoende beheersen. Er bestaat met andere woorden een soort 'representatiecompetentie' of geletterdheid. Een lerende kan deze competentie ontwikkelen via een aantal ontwikkelstappen. In de eerste fase leert men de tekens gebruiken als een iconic depiction van het concept. In een tweede fase ontwikkelen zich visuele symbolische vaardigheden waarbij niet alleen de depiction centraal staat maar ook de symbolische elementen een plaats krijgen. In de derde fase worden de 'iconic symbol signs' gebruikt op syntactische manier, wat betekent dat de tekensystemen gebruikt kunnen worden bij het vergelijken, beschrijven, concluderen, enz.. Er wordt uiteindelijke een eigen representationeel systeem geëxpliciteerd en gebruikt, maar dit is nog niet volledig uitgekristalliseerd. In de vierde fase evolueert men naar een semantisch gebruik van een 'iconic symbol system'. Daarbij wordt er niet enkel gebruik gemaakt van de symbolische tekens, maar kan men die vlot relateren aan andere tekens. Uiteindelijk bereikt een lerende het beheersingsniveau waarbij hij/zij 'iconic symbol signs' kan gebruiken op een reflectieve en rethorische manier. Dit laatste niveau kan enkel bereikt worden na veel oefening.
In deze dissertatie staat de beheersing van het onderliggende 'iconic symbol system' centraal wanneer de geldigheid onderzocht wordt van de CTML in specifieke kennisdomeinen.

Naar aanvullende ontwerprichtlijnen: activatie, training en samenwerken

Het ontwikkelen van multimediale leermaterialen op basis van de CTML-richtlijnen, leidt niet automatisch tot betere leerprestaties. Daarom wordt in dit proefschrift gezocht naar alternatieve, aanvullende ontwerprichtlijnen zoals *activatie*, *training* en *samenwerken*.

Activatie wordt, hoewel het een nieuw element is in het CTML-gerelateerd onderzoek, ook ondersteund door de CTML-theorie. Deze theorie gaat er vanuit dat goed ontworpen leermaterialen de lerenden actief informatie laat verwerken. In dit proefschrift wordt de vraag gesteld of deze activatie niet explicieter naar voor moet komen in het informatieverwerkings-proces dat aan de basis ligt van een studeerproces. Activatie kan benaderd worden via een continuüm dat loopt van volledige activatie tot non-activatie. Tussen beide uiteinden is er een scala aan graden van activatie te onderscheiden. Er is onderzoek beschikbaar dat methoden heeft getoetst om lerenden actiever aan het werk te zetten; evenwel niet altijd gerelateerd aan de CTML.

Een tweede aanvullende ontwerprichtlijn bouwt verder op de theoretische basis die naar voren is geschoven bij activitatie: *training*. Omdat de beheersing van het onderliggende ‘iconic symbol system’ cruciaal zou zijn om leermaterialen in een nieuw kennisdomein te verwerken, wordt voorgesteld om lerenden voor het bestuderen van de materialen éérst een training te geven in het gebruik van het onderliggende ‘iconic symbol system’.

Ten derde wordt de mogelijke waarde van *samenwerkend* leren/collaboratie onderzocht als een ontwerprichtlijn. Uitgaande van o.a. de distributed cognition theory kan er verwacht worden dat het verwerken van informatie of leermaterialen beter verloopt wanneer de verwerking over verschillende cognitieve systemen verdeeld wordt. In een collaboratieve setting kunnen ‘iconic symbol signs’ gezien worden als communicatieve tools waardoor de verwerking gedeeld kan gebeuren. Om deze reden wordt collaboratie ook in het onderzoek opgenomen.

Centrale onderzoeksvraag en onderzoeksdesign voor de verschillende studies

De theoretische onderbouw, kort besproken hierboven en uitgebreid behandeld in het eerste hoofdstuk, helpt de centrale onderzoeksvraag van het proefschrift te duiden. Het hoofddoel van het proefschrift is namelijk onderzoek naar de validiteit van de CTML-richtlijnen in kennisdomeinen die verschillen van deze waarin de CTML oorspronkelijk werd ontwikkeld en onderzocht. We focussen ons in dit proefschrift namelijk op het kennisdomein van de sociale wetenschappen.

Aan deze centrale onderzoeksvraag worden vervolgens vijf afgeleide onderzoeksvragen toegevoegd. De vijf onderzoeksvragen kwamen aan bod in telkens een aparte studie, gerapporteerd in de opeenvolgende hoofdstukken van het proefschrift. De verschillende studies hebben een aantal gemeenschappelijke kenmerken. Zo wordt steeds op dezelfde onderzoekssetting verder gebouwd en worden de onderzoeken bij vergelijkbare onderzoeksgroepen opgezet: eerstejaarsstudenten, pedagogische wetenschappen, ingeschreven voor de cursus onderwijskunde. Ook wordt telkens systematisch een experimenteel design gehanteerd, waarbij de deelnemers at random worden toegewezen aan experimentele condities. Daarbij wordt een pretest-posttest design gehanteerd en worden tussentijdse metingen uitgevoerd van de ervaren cognitieve belasting (cognitive load). In de pretest wordt de voorkennistest m.b.t. de nieuw te bestuderen kennis getoetst. Vervolgens krijgen de respondenten een subset van leermaterialen aangeboden die al dan niet op een andere manier zijn ontworpen (CTML en/of aanvullende ontwerprichtlijnen). Na elk subset wordt een post test afgenomen bestaande uit kennis- en toepassingsvragen. Zoals eerder vermeld, wordt tussentijds ook gevraagd om de ervaren mentale belasting te scoren op een tien punten schaal.

Onderzoeksvragen en samenvatting van de resultaten

De eerste aanvullende onderzoeksvraag wordt behandeld in het onderzoek, beschreven in hoofdstuk twee. Resulteren leermaterialen, ontworpen en ontwikkeld volgens de richtlijnen van de CTML, in het kennisdomein van de sociale wetenschappen, in betere leerresultaten van de lerenden op kennis- en toepassingstesten en lagere niveaus van cognitive belasting? De focus ligt op de veralgemeenbaarheid van de effectiviteit van de CTML-richtlijnen. Centrale vraag was of het toevoegen van ‘iconic symbol signs’ (visuele representaties) aan leermaterialen in het domein van de sociale wetenschappen ook resulteert in hogere scores op kennis- en toepassingsvragen. De onderzoeksresultaten geven aan dat een toepassing van de CTML-richtlijnen niet leidt tot de verwachte positieve effecten. Dit versterkt het vermoeden dat een en ander veroorzaakt kan zijn door een gebrekkige beheersing van het ‘iconic symbol system’ dat is gebruikt bij het uitwerken van de multimediale leermaterialen.

Terwijl in het tweede hoofdstuk de focus lag op het kennisdomein van de sociale wetenschappen, wordt in het volgende onderzoek ook andere kennisdomeinen betrokken. Dezelfde studenten krijgen nu leermaterialen aangeboden uit een vertrouwd en een minder vertrouwd kennisgebied. Verschillen in de beheersing van het onderliggende representatiesysteem zouden kunnen verklaren waarop de leerprestaties op posttesten hoger zijn bij het ‘vertrouwde’ kennisdomein. In een experimenteel onderzoek, gebaseerd op een 2*3 factorieel design, worden 286 eerstejaarsstudenten ad random ingedeeld over zes condities. Voor elk kennisdomein werden drie condities bij de uitwerking van de leermaterialen gevolgd: enkel tekst (T), tekst en visuele representaties (T+V) en visuele representaties met audio (V+A). De resultaten liggen in lijn met de verwachtingen. Voor de meeste subsets aan leermaterialen blijkt dat de CTML-richtlijnen effectiever zijn wanneer de lerenden vertrouwd zijn met het kennisdomein.

In het derde onderzoek wordt onderzocht of het niet beter is om lerenden te activeren bij het gebruik van de multimediale representaties. Er wordt bij de bespreking van dit onderzoek een *activation guideline* geformuleerd waarbij de hypothetische impact van gradaties in activatie wordt onderzocht op leerresultaten en ervaren mentale belasting. De participanten werden ad random ingedeeld tot verschillende condities waarbij ze de volgende multimediale uitwerkingen dienden te bestuderen: enkel tekst (T), tekst en uitgewerkte visuele representaties (T+V), tekst en half uitgewerkte visuele representaties (T+PW) en tekst en het zelf ontwikkelen van visuele representaties (T+D). De onderzoeksresultaten zijn vrij consistent. Hoe meer activiatie, hoe hoger de leerresultaten en hoe lager de ervaren cognitieve belasting (cognitive load).

In een vierde onderzoek wordt aan de activation guideline een *collaboration* guideline toegevoegd. Met andere woorden, er wordt nagekeken of het samenwerken bij het bestuderen van leermaterialen – in globo – het effect van de CTML-richtlijnen en de activation guideline versterkt. De resultaten bevestigen de resultaten van het vorige onderzoek niet. Nu blijken de klassieke CTML richtlijnen weer te primeren; bijv. de leerresultaten zijn significant hoger wanneer tekst met uitgewerkte visuele representaties (T+V) worden bestudeerd. De activatie blijkt negatief beïnvloed te worden door het samen werken. Verklaringen voor deze onverwachte effecten worden naar voren geschoven

In het vijfde en laatste onderzoek wordt nagekeken of het toevoegen van een leerproces en oefening bij het gebruik van ‘iconic symbol system’ een positief effect zou hebben. Op theoretisch vlak kan het hypothetische effect van deze ‘training guideline’ onderbouwd worden. Omdat het beheersingsniveau van het iconisch symbolen systeem in een bepaald kennisdomein een cruciale rol speelt, wordt in de literatuur benadrukt dat lerenden hierin moeten geoefend worden. Enkel door veel om te gaan met de ‘iconic symbol system’, gebruikt in een specifiek kennisdomein, kunnen lerenden vlot de kennisinhouden verwerken en komen tot betere leerresultaten. Daarbij evolueren ze van een novice tot een master. Deelnemers aan het onderzoek werden ad random ingedeeld over verdeeld over vier condities: enkel tekst (T), tekst en visuele representaties (T+V), tekst en het ontwerpen van visuele representaties (T+O), tekst en het ontwerpen van visuele presentaties na training (T+O+T). De resultaten bevestigen de hypothesen niet. De training leidt niet tot de verwachte stijging in leereffect. Ook de impact van de activering blijkt negatief beïnvloed te zijn. De activering blijkt nu niet meer te leiden tot een significant hoger leereffect en tot een significant lagere cognitive belasting.

Het zesde en laatste hoofdstuk presenteert een algemene discussie over de onderzoeksresultaten en komt tot samenvattende conclusies. De resultaten van de verschillende deelstudies bevestigen niet altijd de hypotheses. Toch menen we te kunnen concluderen dat de richtlijnen van de Cognitieve Theorie van Multimedia Leren niet zomaar te veralgemenen zijn naar andere kennisdomeinen. Er moet omzichtig met omgegaan worden in de verschillende kennisdomeinen en er moet tevens de vraag gesteld worden of het in bepaalde domeinen niet beter is activatie of training toe te voegen. Het combineren van verschillende richtlijnen blijkt ook niet steeds te leiden tot de verwachte effecten; bijv. het combineren van activatie en training of activatie en samenwerken.

In het slothoofdstuk worden verder de beperkingen van de studies besproken en worden suggesties voor vervolgonderzoek naar voren geschoven. De beperkingen en suggesties verwijzen naar de noodzaak om onderzoek op te zetten in andere settings en bij andere participanten. Dit laatste betekent vooral dat onderzoek bij meer gevorderde deelnemers nodig, vooral gegeven het feit dat alle onderzoek in deze dissertatie opgezet werd bij novices. Een ander vervolgonderzoek kan respondenten uit sterk verschillende kennisdomeinen onderzoeken die multimediale leermaterialen uit elkaars vakgebied bestuderen. Dit kan helpen de impact van de beheersing van het ‘iconic symbol system’ op een meer accurate manier te bestuderen. Vervolgonderzoek heeft ook baat bij het integreren van aanvullende methodologische technieken. Kwalitatief onderzoek kan helpen om in kaart te brengen hoe lerenden feitelijk omgaan met de alternatieve uitwerkingen van de leermaterialen en/of welke leermaterialen ze verkiezen en/of effectief vinden. Een laatste lijn voor vervolgonderzoek kan zich richten op individuele verschillen. Individuele verschillen kunnen een mediërend of een interactie-effect hebben bij het al dan niet effectief zijn van een bepaalde CTML- of aanvullende ontwerprichtlijn.

Na een bespreking van mogelijke implicaties van de onderzoeksresultaten, wordt het slothoofdstuk beëindigd met een algemene conclusie over de noodzaak om vervolgonderzoek op te zetten naar het ontwerpen en ontwikkelen van leermaterialen. Er wordt aangegeven dat voorliggend proefschrift een eerste stap kan zijn in het verder toetsen van bestaande en nieuwe ontwerprichtlijnen die kunnen leiden tot meer effectieve en efficiënte leermaterialen.

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