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Does cognitive style make a difference?

Consequences of different types of visualization and modalities for learning outcome in relation to visual and verbal cognitive style

A doctoral thesis

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Macht der kognitive Stil einen Unterschied?

Folgen verschiedener Visualisierungsarten und Modalitäten für den Lernerfolg in Bezug auf den visuellen und verbalen kognitiven Stil

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ABSTRACT

This doctoral thesis is based on three quantitative studies conducted on 464 participants. The main goal was to investigate the role of visual-verbal cognitive style when learning with dynamic and non-dynamic learning materials.

The first study revealed important differences regarding the way in which visualizers and verbalizers observe static picture/text combinations in order to learn from them. That is to say that visualizers concentrated mostly on pictures while verbalizers on texts, exhibiting an active way of learning but mostly within textual (verbalizers) or pictorial (visualizers) areas of stimuli. Contradictory to expectations, visualizers did not directly show any supremacy in dealing with pictures, as they did not identify relevant areas sooner than verbalizers. Indirectly though, the results confirmed that verbalizers are less proficient in decoding pictorial information, as they switched to non-informative parts of it sooner than visualizers. Although the retention test did not show any differences on learning outcomes between both groups, visualizers achieved better results on a comprehension test.

The results of the second study confirmed that, when learning with system controlled multimedia environments, spoken explanatory narration brings better results than a written one does. Additionally, an influence of the visual cognitive style on learning with written explanatory text was found. That is, when using a combination of static pictures and written text, higher visual cognitive style comes along with better learning outcome. On the other hand, a combination of higher visual cognitive style, animation and written modality of explanations results in deterioration of learning outcome. The study did not provide any significant results regarding an influence of verbal cognitive style on learning.

In the third study the issues of learner/ system control were addressed, when learning with spoken modality of explanatory text. The results revealed that spoken modality design yielded better outcomes when learning in system-paced design rather than self-paced and with

animation rather than static pictures. In the group of highly developed visualizers though, the combination of static pictures, self-pacing and spoken narration led to a decline of learning outcomes and to cognitive overload. Again, there were no significant results regarding the verbal cognitive style.

The results of the three studies support the assumption of an important role of cognitive style in learning. They indicate a moderating role of visual cognitive style when learning with dynamic and non-dynamic multimedia. This role depends on the design (self-controlled, system-controlled) and modality of explanations (spoken, written) though. Additionally, the differences in gaze patterns between visualizers and verbalizers shed more light on the way in which these two groups of learners retrieve information from multimedia materials. This doctoral research makes a contribution to theoretical research on multimedia learning and cognitive styles, as well as to practical implications on learning materials' design and efficient education.

ZUSAMMENFASSUNG

Diese Dissertation umfasst drei quantitative Studien mit insgesamt 464 Teilnehmern. Dabei war das Hauptziel, die Rolle visueller und verbaler kognitiver Stile beim Lernen mit dynamischen und nicht-dynamischen Lernmaterialien zu untersuchen.

Die erste Studie enthüllte deutliche Unterschiede in Bezug auf die Art und Weise, in welcher Visualisierer und Verbalisierer statische Bild/Text-Kombinationen analysieren, um von diesen zu lernen. Konkret konzentrieren sich Visualisierer primär auf die Bilder, wohingegen Verbalisierer eher auf die Texte fokussieren. Lernende beider Typen weisen jedoch dabei eine aktive Art des Lernens innerhalb ihrer präferierten Stimuli auf. Entgegen der Erwartungen zeigten Visualisierer jedoch keine Überlegenheit im Umgang mit Bildern im Vergleich zu Verbalisierern, da sie keine schnellere und effektivere Identifikation relevanter Bereiche innerhalb der Bilder erzielten. Indirekt bestätigen jedoch die Ergebnisse, dass Verbalisierer weniger Kompetenzen im Umgang mit Bildinformationen aufwiesen, da sie schneller auf die nicht-informativen Bereiche der Bilder wechselten als die Visualisierer. Obwohl der Wissenstest in Bezug auf den Lernerfolg keine Unterschiede zwischen den beiden Gruppen zeigte, erreichten die Visualisierer bessere Resultate im Verständnistest.

Die Ergebnisse der zweiten Studie bestätigten, dass beim Lernen mit einer multimedialen, nichtinteraktiven Lernumgebung eine auditive Erklärung zu besseren Lernergebnissen führt als ein schriftlich dargebotener Text. Zudem konnte ein Einfluss des visuellen kognitiven Stils auf das Lernen mit Texten aufgezeigt werden. Dieser stellt sich durch die Tatsache dar, dass Personen mit einem ausgeprägteren visuellen kognitiven Stil einen besseren Lernerfolg erzielen, wenn eine Kombination aus statischen Bildern und geschriebenem Text verwendet wird. Andererseits kann jedoch eine Kombination aus einem ausgeprägten visuellen kognitiven Stil, Animationen und auditiven Erklärungen wiederum zu einer Verschlechterung

des Lernerfolgs führen. Die Studie konnte jedoch keine signifikanten Ergebnisse in Bezug auf den Einfluss verbaler kognitiver Stile auf das Lernen nachweisen.

In der dritten Studie ging es um den Einfluss interaktiver Kontrollelemente (selbstgesteuert vs. systemgesteuert) beim Lernen mit auditiven Erklärungen oder schriftlichen Texten. Die Ergebnisse zeigen, dass auditive Erklärungen zu besseren Lernerfolgen führt, wenn systemgesteuert statt selbstgesteuert (also nicht-interaktiv) gelernt wird. Zudem zeigte in diesem Fall die Verwendung von Animationen bessere Resultate als die von statischen Bildern. In der Gruppe der „Visualisierer" mit ausgeprägtem visuellen kognitiven Stil führte die Kombination von statischen Bildern, selbstgesteuertem Design und auditiv dargebotenen Informationen hingegen zu einer kognitiven Überlastung und einem Rückgang der Lernerfolge. Auch in dieser Studie gab es keine signifikanten Ergebnisse in Bezug auf den verbalen kognitiven Stil.

Die Ergebnisse der drei Studien unterstützen die Annahme, dass der kognitive Stil eine wichtige Rolle beim Lernen spielt. Insbesondere der visuelle kognitive Stil scheint einen moderierenden Einfluss beim Lernen mit dynamischen und nicht-dynamischen Medien auszuüben. Dieser Einfluss hängt dabei vom Design (selbstgesteuert vs. systemgesteuert) und der Modalität der Erklärungen (auditiv vs. textuell) ab. Zudem konnte durch die Analyse der Blickmuster zwischen Visualisierern und Verbalisierern ein erweitertes Verständnis darüber gewonnen werden, wie die beiden Gruppen unterschiedlich mit Informationen aus multimedialen Materialien umgehen.

Diese Doktorarbeit leistet damit einen Beitrag zur theoretischen Forschung im Bereich des multimedialen Lernens und kognitiver Stile sowie zu praktischen Konsequenzen des Designs von Lernmaterialien zu effektiver Bildung.

CONTENTS

CHAPTER 1

PREFACE

1.1. Introduction

Research on learning with multimedia systematically gains in importance, as usage of new technologies in everyday life increases rapidly. As a result, more and more studies address such issues as the impact of the type of visualization (dynamic vs. non-dynamic; e.g., Höffler & Leutner, 2007; Tversky, Morrison, & Bétrancourt, 2002), type of modality (e.g., Mayer, Dow, & Mayer, 2003; Mayer, 2008; Moreno & Mayer, 1999), range of learner control (system-pacing, self-pacing; e.g., Hegarty, 2004; Tabbers & de Koeijer, 2010), as well as learners' characteristics (among others: spatial ability: e.g., Höffler & Leutner, 2011; Huk, 2006; prior knowledge: e.g., Kalyuga, 2007; 2008; level of ability: e.g., Hannus & Hyönä, 1999; visual-verbal cognitive style: e.g., Höffler, Prechtl, & Nerdel, 2010) on learning outcomes. The studies conducted for this doctoral thesis intended to form a part of this research, shedding more light on the role of cognitive style in the context of multimedia learning. As multimedia learning environments, usually containing pictorial and textual parts, especially refer to visual and verbal cognitive processing (cf. Mayer, 2008; Paivio, 1986), the choice of the visual-verbal dimension for this research seemed to be an obvious one. Most interestingly, the insights into visual-verbal cognitive style's influence on learning with multimedia give an inconsistent view. While some studies seem to confirm the significance of the visual-verbal cognitive style for learning processes (Höffler et al., 2010; Höffler & Schwartz, 2011; Plass, Chun, Mayer, & Leutner, 1998; Riding & Douglas, 1993), other call into question even the very existence of cognitive style (e.g., Kirschner & van Merriënboer, 2013).

This doctoral thesis aims to address these issues systematically - not only by comparing learning outcomes of participants with different levels of visual and verbal cognitive style achieved when learning with diversely designed multimedia, but also by observing such an objective indicator as differences in gaze behavior.

1.2. Structure of the thesis

This doctoral thesis is divided into three parts. The first part presents the theoretical background regarding visual-verbal cognitive style, learning with multimedia as well as eye-tracking methodology used in order to observe learners´ gaze patterns. The theoretical part ends with naming the goals of this doctoral project and short descriptions of studies conducted as part of it. The second section contains three papers, all in the process of review at several scientific journals at the moment, based on the results from the three studies of this project. In the third part an overall discussion, which refers to the goals specified in the first, theoretical part, as well as the theoretical and practical impact of the findings are to be found. As an addition, the thesis contains several appendices giving an overlook of the materials used in this project.

CHAPTER 2

THEORETICAL BACKGROUND

2.1. Cognitive style versus related terms

The history of modern research on cognitive style began in the 1950s and 1960s with works of, among others, Kagan (e.g. 1958, 1965) and Witkin (e.g. 1964; Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). Witkin (1973) explains the essence of cognitive style in following words:

> *From evidence accumulated in the course of more than 20 years of research in many different centers, we now know that all of us have characteristic modes of functioning that we show throughout our perceptual and intellectual activities in a highly consistent and pervasive way. We call these modes of functioning cognitive styles.*
>
> (Witkin, 1973, p. 2).

Messick's (1984) defines cognitive style similarly, as an individually differentiated preferred way of organizing and processing information and experience (cf. Sadler-Smith, 2001). The attractiveness of this psychological construct lies in its potential to link such areas of psychological interest as cognition and personality (Sternberg & Grigorenko, 1997). Or, according to Riding (1997), in playing a role of an interface connecting external and internal reality.

There are, however, other terms, broadly used in research, such as learning style and learning preferences, which are related to the cognitive style term. As Sadler-Smith (2001) noticed, researchers sometimes tend to underrate the need for differentiating these constructs when developing questionnaires. Such insouciance may lead to confusion when considering results of different studies (e.g., Furnham, 1992; Sadler-Smith, 2001). The need for precise discrimination is even more important considering that studies support the assumption of independence of these constructs from each other (Sadler-Smith, 2001). An “onion” model of individual differences proposed by Curry (1983) order the above mentioned constructs in consonance with the level of fixation (from more to less fixed), the level of context-dependency (from less to more dependent), and the level of access to introspection (from less to more accessibility) in the following way: cognitive style, learning style, and learning preferences. Cognitive style is thus the most intrinsic and fixed type of personal characteristics of these three and learning preferences the most extrinsic and context-dependent. Another attempt to shed more light on the cognitive style-related terminology and constructs is the one of Mayer and Massa (2003). The authors compared 14 individual-difference measures and received, as the result of a factor analysis, four factors, namely: general achievement, cognitive style, learning preferences and spatial ability. The difference between cognitive style and learning preferences hark somewhat back to the model of Curry (1983).Cognitive style is, according to Mayer and Massa (2003), the way of thinking, while learning preferences are a kind of behavior, a choice between graphical or textual instructional materials, when learning.

2.1.1. Visual/ verbal cognitive style

A scientific interest concerning the visual-verbal dimension started already in the 19th century along with the works of Francis Galton and Jean Martin Charcot about imagery types (cf. Richardson, 1977) and has led to a large body of research (e.g., Bartlett, 1932; Blazhenkova & Kozhevnikov, 2009; Höffler et al., 2010; Kirby, Moore, & Schofield, 1988; Mayer & Massa, 2003; Paivio, 1971; Plass et al., 1998; Richardson, 1977; Roe, 1951). The contemporary research on visualizers and verbalizers (imagers) is based on the dual-coding theory of Paivio (1978, 1986), which states that a person, when retrieving, organizing and processing visual or verbal information, uses two distinct channels present in the human mind: visual and verbal, and creates in them separate visual and verbal representations. Both visual and verbal representations interact together when recalling information, although there is much evidence supporting the assumption that some people are better at processing information with the verbal channel and others with the visual channel (Mayer & Massa, 2003). The cognitive theory of multimedia learning (Figure 2.1) explains the individual way of processing information by underlying usage of the verbal channel for verbal or auditory representations and the visual channel for visual (pictorial) representations (Paivio, 1978, 1986; Mayer & Moreno, 2003).

The definition of Riding (1994) states that verbalizers process information mainly with usage of "words or verbal associations", while visualizers (or imagers) "experience pictorial mental pictures", when receiving or processing information (Sadler-Smith, 2001, p. 610). Mayer and Massa (2003) define visual-verbal cognitive style as "thinking with words or images" (p. 833).

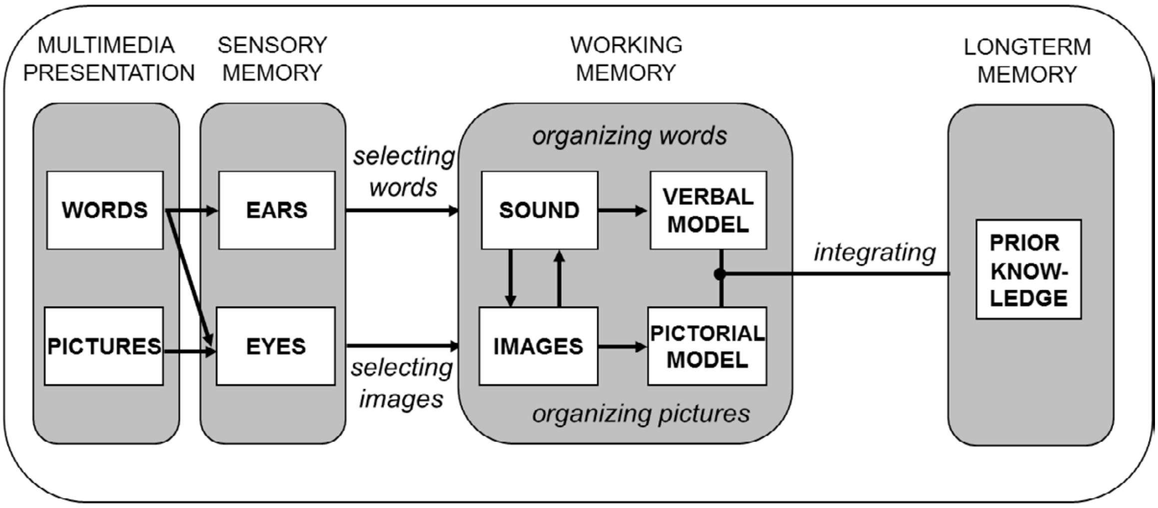

Figure 2.1. Cognitive theory of multimedia learning (Mayer & Moreno, 2003).

Researchers do not, however, consent whether the visual-verbal dimension should be considered as a cognitive style (e.g., Richardson, 1977), learning preferences (e.g., Plass et al., 1998), or a learning style (e.g., Kirby et al., 1988). Hence the research did not bring a clear answer in this matter yet; the decision seems to be arbitrary. In this thesis visual-verbal dimension is understood as the visual-verbal cognitive style according to the definition provided by Mayer and Massa (2003) and in line with the model of Curry (1983). As cognitive style is a construct characterized by a high level of fixation and context-independence along with a low level of accessibility (Curry, 1983), the studies conducted for this thesis aimed to observe the relation between most fixed and context-independent style of performing cognitive processes and achieved learning outcome. Focusing on visual-verbal cognitive style rather than learning preferences or learning style ensures a higher level of external validity and broader range for application of the results. That is why the thesis is based on three studies which use diverse questionnaires regarding visual-verbal dimension and different types of learning environments.

Another controversy with respect to visual-verbal cognitive style refers to its structure. In the study of Mayer and Massa (2003) visual-verbal cognitive style is considered as a one-dimensional construct. One ending of the dimension indicates visual, another verbal style. The authors took into consideration the following questionnaires for visual-verbal cognitive style: the Verbalizer-Visualizer Questionnaire (VVQ) of Richardson (1977) and two own questionnaires: Santa Barbara learning Style Questionnaire (SBLSQ, Mayer & Massa, 2003) and Verbal-Visual Learning Style Rating (VVLSR, Mayer & Massa, 2003). Positive score results indicated visual cognitive style, while negative scores indicated verbal cognitive style. This one-dimensional, dichotomized approach to the visual-verbal cognitive style is not undisputed, however (cf. MacCallum, Zhang, Preacher, & Rucker, 2002). Other researchers (e.g., Paivio & Harshman, 1983) lean to the conclusion that visual-verbal cognitive style consists of two independent dimensions: visual (imagery) and verbal. The authors postulated also a six-factor solution in the Individual Differences Questionnaire developed by Paivio (1971) providing a more detailed description of its structure (Good Verbal Expression and Fluency, Habitual Use of Imagery, Concern with Correct Use of Words, Self-Reported Reading Difficulties, Use of Images to Solve Problems, and Vividness of Dreams, Daydreams and Imagination; Paivio & Harshman, 1983).

One of the newest and most interesting approach to visual-verbal cognitive style is the one by Kozhevnikov and colleagues (Blajenkova, Kozhevnikov, & Motes, 2006; Blazhenkova & Kozhevnikov, 2009; Kozhevnikov, Hegarty, & Mayer, 2002; Kozhevnikov, Kosslyn, & Shephard, 2005). According to this approach, the visual-verbal cognitive style model consists not only of two scales, a verbal and a visual one, but additionally requires the split of the visual scale into two sub-scales, namely an *object imagery scale* and a *spatial imagery scale*. According to Blajenkova et al. (2006), the object imagery scale assesses how pronounced is the individual tendency for building and processing representations with the help of colorful, vivid, and pictorial images, while the spatial imagery scale assesses how pronounced is the individual tendency for building and processing representations with the help of schematic images and spatial transformations or relations. The Object-Spatial Imagery and Verbal Questionnaire (OSIVQ), developed to assess visual-verbal cognitive style according to this approach, shows acceptable internal reliability and construct, criterion and ecological validity (Blazhenkova & Kozhevnikov, 2009). The authors validated the instrument across many studies in which so called *object visualizers* tended to score low on the spatial ability tests, while *spatial visualizers* scored on them highly (Kozhevnikov et al., 2002, 2005). There were also significant differences between professionals in visual arts, science and humanities regarding the scores of the questionnaire: Professionals in visual arts scored higher than professionals in science on the object imagery scale, professionals in science scored higher than professionals in visual arts on the spatial imagery scale, and professionals in humanities scored highest on the verbal scale (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009). Comparable results were also found among college students, when the number of classes in visual art, physics or writing they took was correlated with their OSIVQ scales scores. Positive correlations were obtained between the number of writing classes and the score on the verbal scale, the number of visual art classes and the score on the object imagery scale, and finally between the number of physics classes and the score on the spatial imagery scale (Blazhenkova & Kozhevnikov, 2009). It is worth to underline that the authors did not find significant correlations between the two visual scales of OSIVQ questionnaire and verbal or non-verbal intelligence measures (Blajenkova et al., 2006). On the other hand, other researchers (Riding & Pearson, 1994) found positive, though very low, correlations between the verbal-imagery dimension and intelligence, hence it is not fully adjudicated if the visual-verbal dimension and intelligence are independent from each other. The verbal scale of OSIVQ correlated positively with other verbal tests scores (Blazhenkova & Kozhevnikov, 2009). The assumption of existence of the three dimensions (scales) in visual-verbal cognitive style seems to be broadly supported. The eye-tracking study of Höffler, Koć-Januchta, and Leutner (2016) shows also some evidence indicating that spatial visualizers, object visualizers, and verbalizers show different behavior when learning. Object visualizers tended to concentrate mostly on pictures, while verbalizers preferred to concentrate mostly on texts. Interestingly, spatial visualizers seemed to concentrate on both pictorial and textual parts of the learning material to a comparable extent. This latter study, comparing gaze behavior when learning from combination of pictures and text, leads us to multimedia learning methodology.

2.2. Multimedia learning

Multimedia learning is learning from words and pictures. The rationale for studying multimedia learning is that people can learn more deeply from words and pictures than from words alone. A goal of research on multimedia learning is to understand how to design multimedia learning environments that promote meaningful learning

(Mayer, 2014, p. 1).

The cognitive theory of multimedia learning (Mayer, 2003a, 2008) was built on three major cognitive processing assumptions stating that,

- humans possess two separate mental channels for processing information: visual for processing pictures and verbal for processing words (dual-channel theory: Baddeley, 1992; Paivio, 1986),
- the capacity of these channels is limited (Baddeley, 1986, 1999, 2003; Chandler & Sweller, 1991; Paas & Sweller, 2014; van Merriënboer, 1997),
- in order to learn deeply, individuals must engage such cognitive processes as selection, organization and integration of information with prior knowledge (generative processing: Grabowski, 2004; Mayer, 1996, 2003a, 2003b, 2008, 2014).

A learning situation belongs to the group of cognitively demanding situations and can lead to cognitive overload. The cognitive load theory (Paas & Sweller, 2014; Sweller, 1994, 1999) distinguishes three sources of cognitive load: *intrinsic load* (resulting from basic cognitive activity such as retrieving and processing information), *extraneous load* (generated as a result of cognitive processing of elements irrelevant to the topic, such as, for example, design of the learning environment), and *germane load* (a result of meaningful learning, for example by integrating new information with previous knowledge). If learning is to occur, the cognitive load arisen from all these three sources together may not exceed the working memory resources (Paas, Renkl, & Sweller, 2003). In line with the cognitive theory of multimedia learning (Mayer, 2003a, 2008) and the cognitive load theory (Sweller, 1994, 1999), the individual, when learning, must allocate his/her limited cognitive capacity in order to

- minimize such cognitive processing that is not related to the learning topic and goals (*extraneous processing*, Mayer, 2008, corresponding to extraneous load, see cognitive load theory),
- carry on with basic cognitive processing such as selecting and organizing information relevant to the learning topic (*essential processing*, Mayer, 2008, corresponding to intrinsic load, see cognitive load theory),
- support deep comprehension and integration of the information relevant to the learning topic (*generative processing*, Mayer, 2008 corresponding to germane load, see cognitive load theory).

As creating multimedia learning environment in a way that stimulates deep comprehension is a main goal of multimedia learning (Mayer, 2014), there are several rules (or principles), developed empirically, that support the use of word-picture combinations in a learning process.

2.2.1. Multimedia learning principles

When learning from a combination of pictures and text, learners can experience cognitive overload, especially when learning with animations (Mayer, 2008). There are some ways, though, that can simplify learning with multimedia. The multimedia learning principles help weakening extraneous processing, and, at the same time, continue essential processing and support generative processing (Cao & Nishihara, 2012; Mayer, 2008). The principles are listed below and were also taken into consideration in the research for this thesis.

In accordance with the multimedia learning principles described by Mayer (2008), following principles were applied:

- *Coherence principle:* Learning material should contain topic-relevant information only. The necessity for excluding of incidental material in order to reduce extraneous processing (or extraneous overload) and, eventually, assist deeper comprehension, is supported by many studies (Mayer & Jackson, 2005; Moreno & Mayer, 2000).
- *Redundancy principle:* The learning material should consist of pictures and written text or pictures and spoken text. One should avoid using written and spoken explanatory text simultaneously, in order to avoid additional extraneous load. The saved cognitive capacities may be applied to maintain essential and generative processing (cf. Mayer, 2008; Moreno & Mayer, 2002).
- *Temporal contiguity principle:* One should present related pictorial and textual parts of a learning environment at the same time, synchronously.
- *Spatial contiguity principle:* One should present pictures and texts physically close to each other. Observing both spatial and temporal contiguity principles helps to minimize the extraneous load by giving the possibility to integrate information from the pictorial and textual areas at the same time (temporal contiguity) and without unnecessary scanning through the multimedia materials (spatial contiguity; cp. Moreno & Mayer, 1999; Mayer & Sims, 1994).
- *Voice principle:* When using a spoken narration, one should use a human voice in order to promote generative processing (or germane load). Research (e.g., Atkinson, Mayer, & Merrill, 2005) shows that applying a natural, human-like voice may build a sense of social interaction or cooperation between participants and the computer-based learning environment. This feeling of chatting rather than

interacting with a computer system may awake the need to understand the "partner" and hence foster comprehension (cp. Mayer, 2008).

Several other multimedia principles (Mayer, 2008) were used as a part of experimental design in order to further investigate their influence on learning:

- *Segmenting principle:* One should present animations in learner-controlled portions in order to manage essential processing (or intrinsic load). The facility to adjust the pace of a learning environment to the learner's capability helps to manage basic cognitive processes involved in learning (e.g., Mayer & Chandler, 2001).
- *Modality principle:* One should present animation together with spoken explanatory text rather than with written text, as such form of presentation results in better learning outcome (e.g., Moreno & Mayer, 1999; Mayer et al., 2003). Multimedia learning environments accompanied by a spoken narration should be less demanding for the visual mental channel. The part of learning material provided by a narration is then processed exclusively in the verbal mental channel, and not, as it is at least partly the case when learning with written text, together with pictorial part in the visual channel (cf. Mayer, 2008; Paivio, 1986).

A great research body regarding multimedia learning, its best way of design and its impact on learning outcome was accumulated through the last years. However, the reported results are not always consistent.

2.2.2. Multimedia learning: Static pictures versus animations

Empirical research shows that a combination of pictures and text in learning materials supports and deepens comprehension (e.g. Carney & Levin, 2002; Clark & Paivio, 1991; Fletcher & Tobias, 2005; Hegarty, Carpenter, & Just, 1996; Mayer, 1989, 1997, 2003a, 2008, 2014; Wittrock, 1989). As an example, in the study of Mayer (1989) about a car braking system, students learning from labeled illustrations outperformed control-group students who learned from text without illustrations on problem solving transfer. To give another example: a review of eight studies conducted by Mayer (1997) confirmed that students confronted with text-picture combinations were able to create over 75% more solutions on the problem-solving tests than students who learned from text only. The beneficial effect of multimedia learning lies in its facility to activate both verbal and visual mental channels of an individual in order to process the information (Paivio, 1986) and support effective learning (Fletcher & Tobias, 2005).

A *multimedia effect* (or principle) showing superiority of picture-text combinations over text explanations seems to be sufficiently proven. Hence, the question is not “if” combinations of pictures and text are beneficial to learners but “what kind of combinations” (animated versus static, system-paced versus self-paced, etc.) are “suitable for whom exactly” (more or less advanced learners, with more or less prior-knowledge, lower or higher spatial ability, visual or verbal cognitive style, etc.).

Some studies (e.g., Mayer & Moreno, 2002) seem to support a popular assumption that animations are, on the whole, more advantageous for learners than static pictures. Following the supplantation theory (Salomon, 1979), animations, by providing a direct depiction of motions, help learners in their efforts to understand and mentally visualize a dynamic process, and build a mental model of it. The results of a meta-analysis conducted on 26 primary studies by Höffler and Leutner (2007) also contributed to this assumption. That is, the mean weighted effect size on learning outcome in favor of animations was d=0.37. The effect size was even greater when considering not decorational but representational animation (d=0.40) or when considering highly realistic animations (d=0.76). Still, the results of other studies seem to prove the opposite. For example the study of Mayer, Hegarty, Mayer, and Campbell (2005) showed that learning from static pictures can result in better learning outcomes than learning with animations. In this study students were confronted with instructional material about lightening formation, functioning of a toilet tank, work of ocean waves, and car braking system in two versions: paper-based static pictures with text and computer-based animations with narration. Participants learning from static pictures with text outperformed the animation-with-narration group of participants on retention and transfer tests. Also the review of over 20 studies performed by Tversky et al. (2002) comparing learning with static pictures and animations shows, in the majority of these studies, no advantage of animations over static pictures. The advantage of animations, reported in some studies, derives often from the simple fact that animations provide participants with more information than static pictures (cf. Larkin & Simon, 1987).

A search for an answer to the question why static pictures are sometimes better learning materials than animations leads to the conclusion that beneficial educational impact of animations depends on many additional circumstances.

2.2.3. Multimedia learning: Animations – Advantages and limitations

The effectiveness of animations is not a simple issue and depends on many factors (Hegarty, 2004). One important thing that should be taken into consideration when conducting research with animations is that there are many different types of them. On the whole, researchers usually differentiate between more and less realistic animations, or, in other words, animations that more or less accurately depict the real world, assuming that the first are more effective (Hegarty, 2004; Scaife & Rogers, 1996). There are other opinions in this matter though. For example Rieber, Tzeng, and Tribble (2004) pointed out that realistic animations are not enough to understand the presented problem and verbal explanations are needed in order to enable conceptual understanding. Also Lowe (1999) found out that novices, when viewing realistic animations can be distracted by topic irrelevant but perceptually salient aspects of the display. Sometimes, the non-realistic parts of animations are more beneficial to learners than realistic ones, providing them with information displayed in augmentation in order to make it more obvious or by showing phenomena that are normally invisible in nature (cf. Ainsworth & van Labeke, 2004; Schwan, Garsoffky, &Hesse, 2000). Such a diversity of types of animations makes it difficult to compare and generalize results of research on them.

Another important challenge when using animations is the fact that animations may demand more cognitive resources than static pictures. The demands that animations can impose are closely connected with another important discrimination, namely between non-interactive (system-paced) and interactive (self-paced) types of them (Hegarty, 2004). The problem with non-interactive animations lies in their transient nature. Learners have to view them at a constant rate and in a settled time without the possibility to stop or rewind them. Such a way of display is cognitively very demanding for learners, as they have to constantly integrate momentarily presented information with information presented earlier without the possibility to visit them again (cf. Just & Carpenter, 1986; Hegarty, 2004). Preventing the re-inspection of learning materials can be a great obstacle in the process of comprehension, as eye-tracking research confirms that people usually repeatedly revisit materials when learning (Carpenter & Shah, 1998; Hegarty, 1992, 2004; Mason, Tornatora, & Pluchino, 2013b). A transient way of presenting information can also lead to overlook important information (Ainsworth & van Labeke, 2004). And lastly, non-interactive animations, in comparison to static pictures, can lead to lower cognitive activity, providing learners with a ready-made external model which does not require an application of active learning processes and can inhibit deeper understanding (cf. Hegarty, Kriz, & Cate, 2003; Schwan & Riempp, 2004).

Are then interactive animations problem-free? Does interactivity, by giving the learner the possibility to stop, pause, rewind or fast-forward parts of the learning environment in order to study them more closely, solve all disadvantages of animations? Many studies showed that self-pacing brings advantages to learners, even if the control over the learning environment it offers is minimal (e.g., Hasler, Kersten, & Sweller, 2007; Mayer & Chandler, 2001). Certainly, interactivity solves some of the problems and can be beneficial to learners (e.g., Höffler & Schwartz, 2011) but also brings new ones (cf. Scheiter & Gerjets, 2007), as, for example, the necessity to use an interface, which can provide extraneous cognitive load (Sweller, van Merriënboer, & Pass, 1998). Another problem is motivation and metacognitive skills which are required from learners when learning with interactive animations (Hegarty, 2004). The modality of the explanatory text may also play a role when learning with computer-based multimedia materials. Tabbers, Martens, and van Merriënboer (2001) argue that system-paced environments are more beneficial to learners when accompanied with spoken narration rather than with written text, while in self-paced multimedia the opposite is true: Written text brings more profits to learners than spoken narration. According to Tabbers (2002), spoken narration fits better with non-interactive learning environments because of its passive nature. Namely, as listening to a spoken explanation requires less activity than reading an explanatory text, the first should be more suitable for system-paced learning materials, the latter one with self-paced ones. Still, some researchers argue that individual differences influence learning to a greater extent than the type of media applied in the study (Hegarty, 2004; Zahn, Barquero, & Schwan, 2004). The last assumption leads us to the question: Which individual characteristics of the learner can have an impact on multimedia learning?

2.2.4. Multimedia learning: Individual characteristics of a learner

A researcher interested in individual characteristics of learners and their influence on learning outcome must, sooner or later, refer to the aptitude-treatment interaction (ATI) paradigm and methodology. According to Snow (1991, p. 205):

ATI methodology is designed to take individual differences among treated persons into account systematically in treatment evaluation – to assess the degree to which alternative treatments have different effects as a function of person characteristics and thus determine whether particular treatments can be chosen or adapted to fit particular persons optimally.

Under an aptitude Snow (1991) understands "any measurable person characteristic hypothesized to be propaedeutic to successful goal achievement in the treatment(s) studied" (p. 205). Although the picture emerging from ATI-related studies is rather unclear and inconsistent (cf. Biggs, 2001; Cronbach, 2002; Cronbach & Snow, 1981; Kirschner & van Merriënboer, 2013; Massa & Mayer, 2006), it has an impact on multimedia learning research.

Spatial ability, as "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1994, p. 1000), is considered to be one of the most important aspects influencing multimedia learning, since learning from diagrams and animated displays is a kind of interaction between processes of external and internal visualization (Hegarty & Kriz, 2008). A meta-analysis on 27 experiments (Höffler, 2010) considering an influence of spatial ability on learning with pictorial visualizations resulted in an overall effect of r = 0.34 in favor of high-spatial-ability learners. The meta-analysis showed not only that learners with highly developed spatial ability are in advantage when learning from pictorial visualizations but also supported the assumption that low-spatial-ability learners can profit from dynamic visualizations more than from static ones (cf. Hays, 1996). A comparable effect was reported in the study of Höffler and Leutner (2011), in which students with low spatial ability were outperformed by high-spatial-ability students on learning outcome but only when learning from static pictures. When learning from animations though, both groups of learners received similar results on learning outcome. The authors explained the results in the context of an *ability-as-compensator* hypothesis (Mayer & Sims, 1994) stating that highly developed spatial ability is needed in order to build mental animations from static visualizations, while when learning from dynamic visualizations, spatial ability does not play a significant role (Höffler & Leutner, 2011). In the study of Huk (2006) though, the advantage of highly pronounced spatial ability is explained in the context of an *ability-as-enhancer* hypothesis (Mayer & Sims, 1994). In his study, students with low and high spatial ability received a three-dimensional multimedia lesson on cell biology. It turned out that only high-spatial-ability students could profit from such a visualization, as they had enough cognitive capacity to process information received in that way. Low-spatial-ability students were cognitively overloaded and performed poorly on a subsequent learning outcome test (Huk, 2006). To summarize: Although the impact of spatial ability on learning outcomes when learning with the usage of a multimedia environment is strongly supported by research results, the conclusions of this research are inconsistent and difficult to interpret.

Another individual characteristic of a learner which can have a significant influence on multimedia learning is prior knowledge (ChanLin, 2001; Kalyuga, 2007; 2008). In the study of Kalyuga (2008), 33 university students were divided into two groups: novices and experts on linear and quadratic functions transformation. Afterwards, they were learning from either animated or static diagrams (without explanatory text). It turned out that novices gained more knowledge when learning from static pictures while experts benefitted more from animations. This result represents, according to the authors, an *expertise reversal effect*, which explains why novices need more guidance when learning than experts (cf. Kalyuga 2007; 2008; Kalyuga, Ayres, Chandler, & Sweller, 2003). That is to say that novices, in contradiction to experts, do not have any structured prior knowledge on the presented topic to aggregate it with the newly received information. Hence, this structure or schema should be given to them during learning. Experts can perceive too much instruction or external support in processing information as an obstacle hindering them from processing information on their own: absorbing the new information and combining it with the structures of knowledge they already have (cf. Schnotz & Rasch, 2005). Mayer and Moreno (2003) assume that the difference between needs of novices and experts when learning can be explained in terms of cognitive load theory. That is, for novices, some learning environments can be too cognitively demanding, as they cause cognitive overload by, for example, giving too little time to process and structure the information. Results provided by a study of ChanLin (2001) seem also to support that assumption, as in this study less experienced students learned better with less cognitively demanding static illustration (cf. Hegarty, 2004), while more experienced ones learned comparably good with animations, static pictures and text.

2.2.5. Multimedia learning and visual/ verbal cognitive style

Results regarding an influence of spatial ability and prior knowledge on learning with animations and static pictures encouraged researchers to look for other moderators in multimedia learning. However, the results give an ambiguous picture.

In the study conducted by Riding and Douglas (1993), 59 students of secondary schools were tested with the Cognitive Styles Analysis (CSA; Riding & Cheema, 1991), in order to assess their cognitive style (verbal-imagery and wholist-analytic dimensions), and presented with two kinds of computer presentation about the car braking work: text-plus-text and text-plus-picture. The study showed that imagers outperformed verbalizers in the text-plus-picture condition while in the text-plus-text condition the opposite was true: Verbalizers outperformed imagers on post-knowledge test. Comparable results received Plass et al. (1998) when testing students enrolled in a German language course. Students classified as verbalizers (in terms of learning preferences) benefited (in terms of comprehension of the given text) more from verbal explanations to presented text than visualizers, whereas visualizers benefited more from pictorial explanations than verbalizers. On the other hand though, Massa and Mayer (2006) could not find such an effect, namely the authors could not find any strong evidence supporting the ATI hypothesis concerning the visual-verbal dimension: Visualizers and verbalizers did not differ on post knowledge test scores. The observed inconsistency in the results of these studies can be caused by the differences in the way of classification of the participants into groups of visualizers and verbalizers. Plass et al. (1998) classified students as visualizers or verbalizers according to results of an analysis of their preferences for visual or verbal information, whereas Massa and Mayer (2006) used a set of 14 cognitive measures linked with the visual-verbal dimension.

The research on visual-verbal-dimension influences on learning with static pictures and animation does not bring a clear picture either. In the study of Höffler et al. (2010) learners with a highly developed visual cognitive style achieved better learning outcomes when learning with static pictures than with animations. Among less developed visualizers the type of presentation seemed not to play a significant role: Their learning results were similar when learning with static pictures or with animations, but, generally, poorer than the learning outcome achieved by highly developed visualizers. These results seem to support, at least partly, the ability-as-compensator hypothesis, assuming, as it was the case with spatial ability (cf. Höffler & Leutner, 2011), that highly developed visual cognitive style is needed when constructing mental representation of the process on the basis of static pictures. Additionally, the results from the study of Höffler et al. (2010) seem to suggest that a more pronounced visual aptitude might be an obstacle when learning from animations. If we perceive animation as a kind of facilitation, giving learners a “ready-made” depiction of a process, than, analogously to the expertise reversal effect (Kalyuga et al., 2003), highly developed visualizers should learn better with static pictures, as they allow them to create their own schema of the process. In that case, animations should be more beneficial for less developed visualizers or verbalizers, giving them a “ready-made” external representation. Results found by Höffler and Schwartz (2011) do not support these assumptions though, as in their study visual learners benefited more from animations, while verbal learners tended to profit more from static pictures (similar also Chen & Sun, 2012). One can speculate that animations, as a possible cause for cognitive overload (Hegarty, 2004), may hinder learning process in the group of verbalizers. Still, the results are highly dependent on the type of animation used in the respective project.

All in all, there is strong evidence supporting the assumption that visualizers and verbalizers learn in different ways. Even more evidence to it can be found in studies using eye-tracking methodology.

2.3. Eye-tracking methodology

Visual attention has been an object of psychological interest for more than hundred years (cf. Heijden, 1992). Its history is connected with the history of eye-tracking, since it is assumed that eye movements are related to one’s path of attention (Duchowski, 2007). This connection provides the basic assumption that eye movements are related to the intensity and direction of attention (e.g., Bucher & Schumacher, 2006), but, at the same time, introduces the basic problem in eye-tracking research. That is, it is difficult to state how this relation between attention and eye movements actually works and what the observed eye movements mean (cf. Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & van de Weijer, 2011).

Most reported types of events in eye tracking data are: a *fixation* – “the state when the eye remains still over a period of time, for example when the eye temporarily stops at a word during reading” (Holmqvist et al., p. 21) , a *saccade*, which is “the rapid motion of the eye from one fixation to another (from word to word in reading, for instance)” (Holmqvist et al., 2011, p. 23), and a *regression,* which is a specific type of saccades moving “backwards within a single word" or backwards "to a previously fixated word" (Holmqvist et al., 2011, p. 264). A gaze path of a multimedia learner is presented in Figure 2.2.

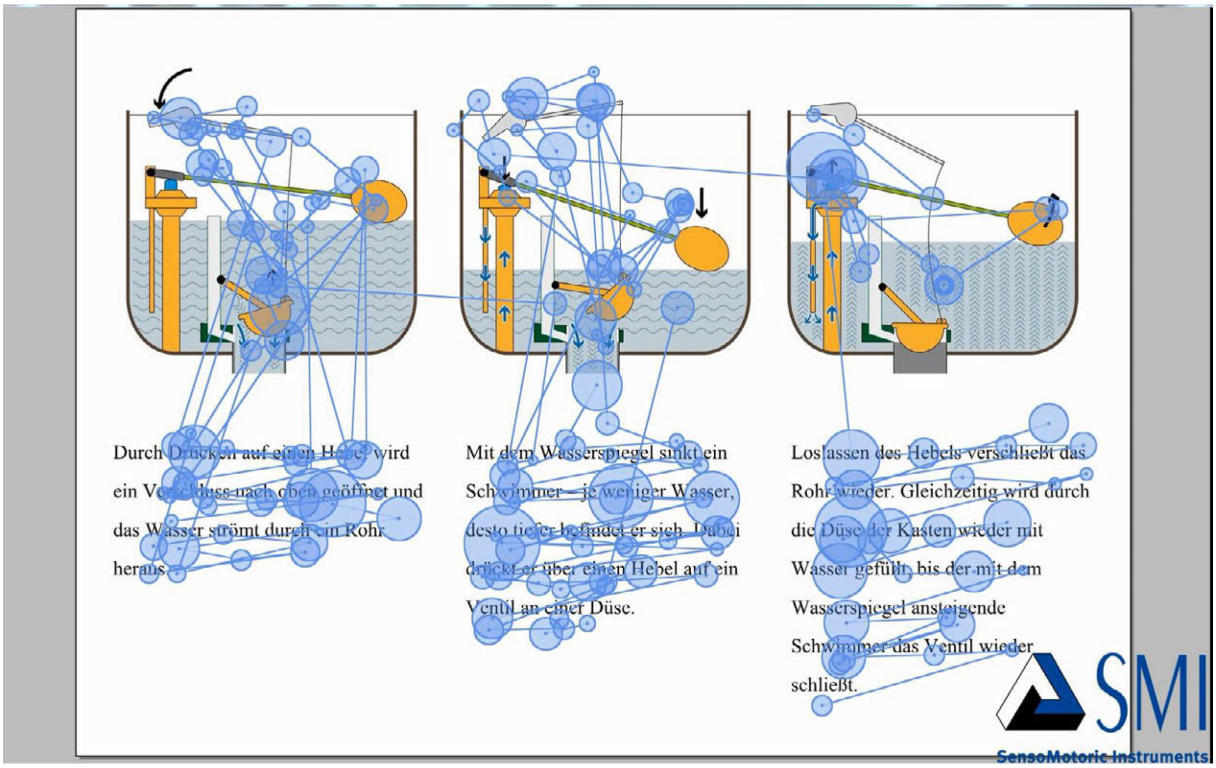

Figure 2.2. A sample of a learner's gaze path. Circles indicate fixations, links indicate saccades.

The eye-mind assumption states then that the length of fixation on a word indicates the length of cognitive processing of this word (cf. Just & Carpenter, 1980). The research on eye-tracking and text comprehension, especially on dyslexic participants, proved that dyslexic children make more saccades and regressions than non-dyslexic ones regardless of the language they were speaking (e.g., De Luca, Borrelli, Judica, Spinelli, & Zoccolotti 2002; Dürrwächter, Sokolov, Reinhard, Klosinski, & Trauzettel-Klosinski, 2010; Rayner, 1998). These results support the eye-mind assumption showing that eye movements can illustrate difficulties in processing information. On the other hand, Holsanova, Holmberg, and Holmqvist (2008) found out that although increased frequency of saccades between text and pictures can indicate difficulties in integrating information from both sources, it can also be a sign of a high interest in integrating them. This result may illustrate the difficulties in interpreting meaning of eye movements.

Eye tracking researchers admit that even if attention (and other cognitive processes) is connected with the gaze direction and its length, it is also possible to separate attention from the gaze direction (Duchowski, 2007). In other words: Looking at something does not necessarily mean thinking of it. For example, the prolonged looking at a stimulus can have nothing to do with the stimulus, as the participant's thoughts can be totally unrelated to it (Hyrskykari, Ovaska, Majaranta, Räihä, & Lehtinen, 2008). Triesch, Ballard, Hayhoe, and Sullivan (2003) proved that even looking straight at the stimulus related to the performed task does not necessarily lead to any cognitive activity related to that task, as it does not lead to the working memory activity. Another problem is again the interpretation. Even though a long dwelling on a stimulus can indicate interest in it, it can be also an indicator of difficulties or confusion (Hyrskykari et al., 2008). On the other hand, it is also possible to process information at which we do not look. Griffin and Spieler (2006) reported in their study that participants are able to give explanations to stimuli on which they did not fixate their gaze. Still, in spite of all its limitations, eye-tracking methodology is broadly used in research including more and more areas of knowledge, from cognitive sciences, psycholinguistics, and education to marketing and sport. The reason for that is that, as attention processes cannot be directly observed, research must rely on indirect indicators such as, among others, eye movements. The eye-mind assumption, even though criticized and argued, stands firm and gained new evidence recently (e.g., Chen, Clarke, Watson, MacLeod, & Guastella, 2015; Harrison & Gibb, 2015). Concluding, the question is not "if" to use eye-tracking methodology in research, but more, "how careful" we should be when interpreting its results.

The development of research on visual attention led to the development of eye trackers – the first were already built in the late 19th century (Holmqvist et al., 2011). The most common way to measure human gazes is to track the reflection of the pupil and cornea (Holmqvist et al., 2011; Hansen & Ji, 2009). In today's use are mostly three types of eye-trackers, namely tower-mounted eye-tracker, remote eye-tracker and head-mounted eye-tracker. All three types differ in terms of the level of restraint of participants head movements and the range of application. The stimuli, when using remote eye-trackers, are presented on a monitor, and it is easier for participants to behave naturally during the examination, since nothing is attached to their head (cf. Holmqvist et al., 2011). This type of an eye-tracker is considered relatively easy to operate and was used in the research for this thesis.

2.3.1. Eye-tracking and multimedia learning

Learning from multimedia materials can be demanding and consumes limited working memory capacities (e.g., Chuang & Liu, 2012; Mayer, 2008), as participants must divide their attention between textual and pictorial parts of presented materials. In order to provide more information regarding the way in which this attention split occurs, many studies have been conducted investigating eye movements when learning with multimedia environments.

On the whole, studies support the finding that attention of participants in multimedia learning environment is driven mostly by text (cf. Schmidt-Weigand, Kohnert, & Glowalla, 2010; Hannus, & Hyönä, 1999). In the study conducted by Hannus and Hyönä (1999) 10-year-old elementary school children inspected pictures only minimally when learning from science textbook materials and paid attention mostly to the text. Interesting results brought a study of Rayner, Rotello, Stewart, Keir, and Duffy (2001) regarding eye movements when looking at print advertisements. Although the viewers of advertisements spent more time looking at textual parts and made more fixations on them comparing with pictorial parts of ads, the fixation durations and lengths of saccades were both longer when viewing pictures.

Studies showed that participants differ in patterns of viewing picture-text combinations as well as in patterns of reading text. Hyönä, Lorch, and Kaakinen (2002) pointed out that the most effective pattern in reading is to pay close attention to headings and perform topic relevant regressions rather than to read a text in a linear way. They performed a study in which they asked university students to read two multiple-topic expository texts in order to summarize their contents afterwards. It turned out that the strategical way of reading, when a reader concentrates on most relevant parts of the text instead of reading the whole text progressively, resulted in better comprehension of the text. Similar results are to be found in the study of Jarodzka, Scheiter, Gerjets, and van Gog (2010) with experts and novices. In this study participants were observing four videos displaying a swimming fish and were asked to describe locomotion patterns of it. Eye movement analysis showed that experts concentrated more on the relevant aspects of the fish movements than novices. Additionally, the study of Hannus and Hyönä (1999), containing a comparison of low-ability and high-ability pupils when learning from text-pictures materials, showed differences in eye movements patterns between these two groups. Authors distinguished between low- and high-ability pupils on the basis of scores achieved in the Raven's Progressive Matrices (Raven, Court, & Raven, 1992). High-ability children displayed a more strategic way of viewing texts and pictures than low-ability ones, that is they spent more time looking at the relevant parts of the learning materials. High-ability pupils spent also more time looking back and forth between the pertinent parts of pictures and texts than low-ability pupils. On the other hand, low-ability children spent more time viewing non-relevant blank parts of the stimuli (Hannus, & Hyönä, 1999).

The eye movements when learning, as well as the quality of learning outcome, depends not only on the personal traits of the learner but also on the way in which the learning materials are designed. According to the research conducted by Holsanova et al. (2008), the shorter the physical distance between textual and pictorial parts of the stimulus is, the easier it is for participants to find connections between them and to mentally integrate both pictorial and textual information. Materials which are spatially structured into a serial layout also give learners the best chance to integrate information from text and pictures. Holsanova et al. (2008) observed eye movements of participants when reading a newspaper and confirmed that spatial contiguity between text and pictures as well as a serial format of the material facilitates concentration of attention and cognitive processing. Similar effects report Johnson and Mayer (2012) in their study in which they presented to participants, using different layouts, a multimedia material about car brakes. Participants who learned from integrated materials with diagrams and descriptions placed directly near to each other performed better on a transfer test score than participants who learned from materials in which diagrams and descriptions were presented in separate paragraphs. Thus, the authors of the study underline that spatial contiguity supports learning and improves learning outcomes (cp. multimedia learning principles; Mayer, 2008). On the other hand, many studies show that readers tend to choose one source of information (pictures or text) and ignore the other one, when they interpret them as independent from each other and as self-contained (Holsanova et al., 2008).

The crucial challenge in learning is the integration of information. As explained above, this can be facilitated by a serial format or a spatial contiguity of texts and pictures. An eye-tracking study of Mason et al. (2013b) identified three different patterns of eye movements among fourth grade pupils when learning from illustrated science texts, varying in terms of level of integration of text and pictures. The authors found, as expected, a high connection between a highly integrative way of viewing text-picture learning materials and high learning outcomes. The study of Schmidt-Weigand et al. (2010) on students learning from multimedia instruction on the formation of lightning showed additionally that participants spend more time inspecting animations when the accompanying text is spoken than when it is written.

Hence, a spoken-text condition enables them to benefit more from animations than a written-text condition and to better integrate information from them. Finally, the study of Mason, Pluchino, Tornatora, and Ariasi (2013a) stated that abstract pictures (that is, depicted in a schematic way, as a graph) promote integration of the information retrieved from verbal and pictorial parts of the stimulus better than concrete illustrations, depicted in a contextualized way.

Concluding, attention in multimedia learning environments is driven mostly by text (e.g., Hannus, & Hyönä, 1999; Schmidt-Weigand et al., 2010). However, individuals differ in terms of patterns applied when reading or viewing multimedia materials (Hyönä et al., 2002; Mason et al., 2013b). The most effective way is to pay attention to the materials' most relevant parts rather than to inspect the materials in a progressive or linear manner (e.g., Hyönä et al., 2002). There are several facets though which can influence the way of inspecting multimedia stimuli, among them the level of knowledge on the topic as well as the level of ability (cp. Jarodzka et al., 2010; Hannus and Hyönä, 1999). The design of multimedia materials may promote integration of information retrieved from both pictorial and textual sources and, as a consequence, deepen comprehension (Holsanova et al., 2008; Johnson & Mayer, 2012; Mason et al., 2013b). All in all, as there are many different traits which can influence visual behavior of participants, the question arises if cognitive style is also one of them.

2.3.2. Eye-tracking and visual/ verbal cognitive style

Not only high-ability and low-ability students or experts and novices differ in their way of viewing multimedia materials (cf. Hannus & Hyönä, 1999; Jarodzka et al., 2010). Some studies show that the visual-verbal dimension can also influence visual behavior of individuals, although there is rather moderate research available on it at the moment.

The study of Tsianos, Germanakos, Lekkas, Mourlas, and Samaras (2009) investigated students' visual behavior when participating in an e-learning course about algorithms in computer science. Authors used the Cognitive Style Analysis (CSA) instrument (Riding & Cheema, 1991) in order to assess the imager/ verbalizer axis of cognitive style. They distinguished three groups of participants: imagers, verbalizers and intermediates. They calculated the ratio of images to text fixations and found significant differences among the three groups of participants. It turned out that imagers concentrated mostly on pictures, verbalizers on verbal content, while intermediates viewed both text and illustrations to a comparable extent. This study not only displayed differences in visual behavior among participants demonstrating different cognitive style, but also confirmed the very existence of a cognitive style (or learning style), which is not always taken for granted (cf. Kirschner & van Merriënboer, 2013).

The study of Mehigan, Barry, Kehoe, and Pitt (2011) also shows that eye-tracking can detect and, in a way, confirm participants' learning style by investigating their mouse movement pattern or their eye movements. Students participating in the study were completing the Felder-Soloman Index of Learning Styles (Felder & Soloman, n.d.) in order to identify among them visual and verbal learners. The study confirmed differences in gaze patterns between different learners. Correlations between learning style and overall focus duration showed that visual learners tended to focus longer on visual parts, while verbal learners focused longer on verbal parts of the learning material. Similar effects received Cao and Nishihara (2012) in their study with an interactive slide online video. They also assessed participants' learning style using the Index of Learning Style (ILS) questionnaire derived from the Felder-Silverman Learning Style Model (FSLSM, Felder & Spurlin, 2005). One of the dimensions present in this model is the visual/ verbal dimension indicating if a learner prefers textual or visual materials. The authors, as they failed in finding dominant verbal learners among the participants, confirmed that the strong visual group differed from the intermediate visual group in terms of eye movements. The visual group learners demonstrated longer mean viewing time on pictures than the intermediate group.

These first studies showed promising results and served as an encouragement to continue research on the visual-verbal cognitive style in terms of visual behavior and learning outcome.

CHAPTER 3

OVERALL GOALS AND RESEARCH QUESTIONS OF THE DOCTORAL PROJECT

The doctoral project aims to contribute to the research regarding the visual-verbal cognitive style and its role when learning with diverse types of multimedia environments. The research questions of the doctoral project can be grouped in three general blocks:

a) Cognitive style and type of visualization:

- Do dynamic visualizations (animations) have an overall advantage over non-dynamic visualizations (cf. Höffler & Leutner, 2007)? Will rather the opposite be true (cf. Tversky et al., 2002)?
- Does the type of multimedia (dynamic or non-dynamic) interact with the level of visual-verbal cognitive style (cf. Höffler et al., 2010; Höffler & Schwartz, 2011)? Does type of pacing (system-pacing versus self-pacing) play any role in this interaction?
- Will the results regarding visual-verbal cognitive style and type of visualization support the ability-as-compensator hypothesis (cf. Höffler & Leutner, 2011) rather than the ability-as-enhancer hypothesis (cf. Huk, 2006)?
- Will the expertise reversal effect (cf. Kalyuga 2007; 2008) occur, that is, will too much of external support, provided by the animation, hinder learning in the group of experts in pictures, that is, visualizers?

b) Cognitive style and type of modality:

- Will the modality effect be replicated (cf. Mayer, 2008)? That is, will learners profit better from multimedia environments accompanied by a spoken narration rather than a written explanatory text?

- When learning from multimedia materials accompanied by a spoken narration, are the system-paced environments, not self-paced ones, better for learners (cf. Tabbers et al., 2001)? In other words, are the benefits of self-pacing (cf. Mayer & Chandler, 2001; Schwan & Riempp, 2004; Tabbers & de Koeijer, 2010) moderated by the modality of the explanatory text (cf. Tabbers, 2002)?
- What is the role of visual-verbal cognitive style when learning with different modalities? Namely, is the partial ability-as-compensator effect from the study of Höffler et al. (2010) moderated by the modality of the explanatory text?

c) Cognitive style and gaze behavior:

- Will visualizers and verbalizers view static multimedia learning materials in different ways? Will visualizers spend more time inspecting pictures, while verbalizers will spend more time inspecting texts (Mehigan et al., 2011; Tsianos et al., 2009)?
- Will visualizers, as kind of experts in decoding pictures, be better in finding relevant areas in pictorial parts of multimedia materials (cf. Hannus & Hyönä, 1999; Jarodzka et al., 2010)?
- Will both groups of learners (visualizers and verbalizers) use the integrative way of viewing stimuli, which is regarded best for learning (cf. Mason et al., 2013b)? Will visualizers, profiting better from text-picture combinations (Riding & Douglas, 1993; Höffler et al., 2010), perform better on learning outcome than verbalizers?

This doctoral project was a part of the project ELLSA ("The Influence of Visual and Verbal Cognitive Style on Learning with Static Pictures or Animations in Computer-Based Learning Environments", funded by the German Research Fondation, DFG, grant no. HO 4303/6-1), which focused on the impact of individual characteristics of learners such as cognitive style on learning with dynamic and non-dynamic visualizations accompanied by explanatory text in order to optimize the use of "new media" in education of nature sciences. In order to answer the research questions of the doctoral project, three studies were conducted, which resulted in three papers. All three of them are under review in peer-reviewed journals at the moment. Short descriptions of these manuscripts are provided below. For an overlook of the materials used in the doctoral project, please see the appendices.

Visualizers versus verbalizers:

Effects of cognitive style on learning with texts and pictures – An eye-tracking study

The first manuscript describes a study conducted with usage of a SMI RED 120 Hz Eye Tracking system aiming to examine differences between visualizers and verbalizers in terms of their gaze behavior when learning with text-picture static combinations. 32 students of Kiel University, chosen out of about 90 prospective candidates, characterized by a strongly pronounced either verbal or visual cognitive style, viewed two different multimedia stimuli depicting the learned helplessness phenomenon and the functioning of a toilet cistern. Results have shown several meaningful differences between both groups of participants on eye movement patterns as well as on learning outcome.

Does modality play a role?

Visual-verbal cognitive style and learning with static pictures versus animations

The second manuscript reports results of a study which focused on learning with computer-based environments: dynamic (animation) versus non-dynamic (a series of static pictures) visualizations accompanied by explanatory text either in written or spoken form. A group of 197 students from University of Kiel, mostly biology majors, watched a 10 min. learning session on the primary reactions in photosynthesis twice. The learning environment was system-paced. The results were in line with the modality principle (Mayer, 2008), additionally revealing an interaction effect of visual cognitive style, type of modality (spoken versus written) and type of visualization (animation versus static pictures).

Effects of pacing and cognitive style
on learning with dynamic and non-dynamic visualizations with narrative explanations

The third manuscript reports results of a study which focused on learning with dynamic (animation) versus non-dynamic (a series of static pictures) computer-based visualizations displayed in a system-controlled (system-paced) or learner-controlled (self-paced) way. A group of 235 biology students from the University of Kiel and the University of Potsdam was watching a learning session depicting the primary reactions in photosynthesis. All versions of learning environments were accompanied by a spoken narration. Significant effects regarding the role of the type of pacing (self-pacing versus system-pacing) as well as the type of visualization (animation versus static pictures) were received. Additionally, the study contributed to the discussion on the relation between visual cognitive style and learning outcome when learning with diverse types of computer-based environments.

CHAPTER 4

VISUALIZERS VERSUS VERBALIZERS: EFFECTS OF COGNITIVE STYLE ON LEARNING WITH TEXTS AND PICTURES - AN EYE-TRACKING STUDY

Abstract: This study was conducted in order to examine the differences between visualizers and verbalizers in the way they gaze at pictures and texts while learning. Using a collection of questionnaires, college students were classified according to their visual or verbal cognitive style and were asked to learn about two different, in terms of subject and type of knowledge, topics by means of text-picture combinations. Eye-tracking was used to investigate their gaze behavior. The results show that visualizers spent significantly more time inspecting pictures than verbalizers, while verbalizers spent more time inspecting texts. Results also suggest that both visualizers' and verbalizers' way of learning is active but mostly within areas providing the source of information in line with their cognitive style (pictures or text). Verbalizers tended to enter non-informative, irrelevant areas of pictures sooner than visualizers. The comparison of learning outcomes showed that visualizers outperformed verbalizers on comprehension.

Keywords: cognitive style; verbalizer; visualizer; eye-tracking; multimedia learning

Koć-Januchta, M., Höffler, T. N., Thoma, G. B., Prechtl, H., Leutner, D. (submitted). Visualizers versus verbalizers: Effects of cognitive style on learning with texts and pictures - An eye-tracking study.

Issues of cognitive style and learning preferences have been an underlying topic of educational and psychological discussions for years but were not always followed by extended research. Sometimes the whole concept is disputed (e.g., Kirschner & van Merriënboer, 2013), sometimes endorsed (e.g., Cassidy, 2004). Regarding visual/ verbal cognitive style and its influence on learning from text-picture combinations, relatively few studies have been conducted. There are even fewer studies which try to examine actual differences between visualizers and verbalizers via a direct observational method like, for example, eye-tracking.

Our study is therefore an attempt to directly examine verbal and visual learners' eye-movements in the context of multimedia learning. Some eye-tracking studies already indicated that visualizers and verbalizers might differ in the way they view pictorial and textual stimuli (Mehigan et al., 2011; Tsianos et al., 2009). Thus, when learning with texts and pictures, learners' visualizer-verbalizer cognitive style might have a direct influence learning behavior and preferences. Such a finding would help proving the existence or non-existence of different cognitive styles and their influence on learning behavior and, furthermore, learning outcome.

As there is considerable lack of consensus regarding the terminology in case of cognitive style, our theoretical discussion begins with a definition of what we understand when writing about cognitive style.

4.1. Theoretical background

4.1.1. Cognitive style, learning style, or learning preferences?

According to Messick (1984), cognitive style can be defined as an individual difference in the way of organizing and processing information. Sternberg and Grigorenko (1997) described cognitive style as a "bridge" placed between cognition and personality.

Often, studies on cognitive style focus on the visualizer-verbalizer dimension, which originally derives from dual-coding theory (Paivio, 1986). According to this theory, incoming information is processed and mentally represented in two ways: verbally and visually. Hence connecting these two mental representations should improve learning outcomes (e.g., Mayer, 2014). Although there is much evidence that some people tend to think in words and others in pictures (e.g., Mayer & Massa, 2003), there is some controversy as to the impact of this distinction on learning behavior and learning outcome (Kirschner & van Merriënboer, 2013; Massa & Mayer, 2006).

Furthermore, there is great inconsistency in the literature on how to refer to the distinction of visualizers and verbalizers: Some researchers refer to the term cognitive style (e.g., Richardson, 1977), others to learning style (e.g., Kirby et al., 1988), or learning preferences (e.g., Plass et al., 1998). As a result of a factor analysis, Mayer and Massa (2003) identified cognitive style, learning preferences, and spatial ability as three different factors. They distinguished between these three constructs, defining spatial ability as a specific type of cognitive ability, visualizer-verbalizer cognitive style as thinking in pictures or words, and learning preferences as preferences in choosing graphics or text in instructional materials. Based on this distinction, the current study's focus is on cognitive style. We focus on differences between learners who think either more in pictures (visualizers) or in words (verbalizers). Learning preferences, as well as the correlated construct learning style, we understand as a predilection for specific kinds of learning materials (verbal, visual), that can be, but not necessarily has to be a consequence of cognitive style.

Research results are also inconsistent in terms of the structure of the visualizer-verbalizer distinction. Some studies describe this distinction as a one-scale dimension, which two endings correspond to either verbal or visual cognitive style (Mayer & Massa, 2003), others as two different scales. Kozhevnikov et al. (2005) even subdivided the visual scale into two subscales: object and spatial. Object visualizers score poorly on spatial imagery tasks, whereas spatial visualizers score highly. The authors reported that many scientists and engineers seem to be spatial visualizers, while visual artists are usually rather be categorized as object visualizers. As the question on the number of scales does not seem to be fully answered yet, we used a large number of different established scales in our study to be able to satisfyingly characterize visualizers and verbalizers. Furthermore, we studied the learning behavior of visualizers and verbalizers in learning tasks which consist of visual (that is, pictorial) and verbal representations.

4.1.2. Learning with text and pictures

Many studies (Clark & Paivio, 1991; Mayer, 2014; Wittrock, 1989) show that a combination of text and pictures supports learning and deepens understanding and problem-solving processes. For example, in a study conducted by Plass et al. (1998) on visualizer/verbalizer learning preferences, a combination of text and pictures or text and animations led to better learning outcomes than text alone. However, simply combining text and pictures does not always lead to improvements of learning results. The effectiveness of the combination is highly dependent on such aspects as the form of visualization, the type of learning task, the number of referential connections between text and pictures, and personal characteristics of the learner (e.g., Mayer, 2014; Schnotz & Bannert, 2003). Thus, learning achievements differ with respect to individual differences, such as, for example, prior knowledge (e.g., Kalyuga, 2007), spatial ability (e.g., Hegarty, 2005; Höffler, 2010; Höffler & Leutner, 2011), or cognitive style (Höffler et al., 2010).

According to the cognitive theory of multimedia learning (Figure 4.1) individuals process information using two channels: verbal for verbal or auditory representations and visual for visual or pictorial representations (Paivio, 1986; Mayer & Moreno, 2003).

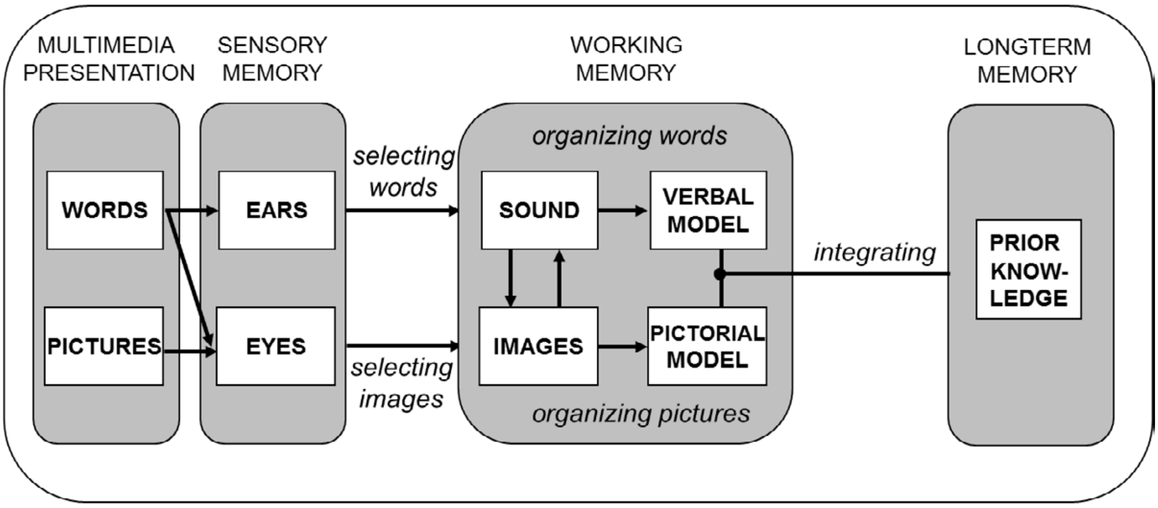

Figure 4.1. Cognitive theory of multimedia learning (Mayer & Moreno, 2003).

Verbal and visual processing is also reflected in the structure of working memory postulated by Baddeley (1998). The capacities of visual and verbal components of working memory (phonological loop and visuospatial sketchpad) are limited (Baddeley, 1998; Chandler & Sweller, 1991), differ strongly depending on individual differences such as intelligence (Baddeley, 2003), and are deeply connected with cognitive load experienced by an individual (cognitive load theory; Sweller, 1994). The more difficult the learning material, the higher the perception of intrinsic load (Plass, Moreno, & Brünken, 2010). Some studies show that working memory capacity and cognitive style (in this case, so called field dependence/independence cognitive style) are correlated (Mousavi, Radmehr, & Alamolhodaei, 2012). Referring to these findings, we make assumptions regarding the way in which visualizers and verbalizers might process information in multimedia learning differently. We assume that limited capacities of working memory's components and individual differences regarding cognitive style can result in favoring either the verbal or visual channel while processing information in multimedia learning (Mayer & Massa, 2003).

Visualizer-verbalizer cognitive style seems to have an impact on the learning process. Visualizers achieve better when learning from pictures and text and profit more from pictorial information, while verbalizers rely more on text (e.g., Höffler et al., 2010). Also, Riding and Douglas (1993) showed that text-picture combinations are more beneficial to visualizers, whereas conditions providing textual information only result in better results for verbalizers. These findings can support our assumptions and also suggest that visualizers might be better in integrating information represented in both channels described in the cognitive theory of multimedia learning. Moreover, Plass et al. (1998) showed that the absence of the preferred mode of information presentation (e.g., pictorial for visualizers) resulted in poorer learning. On the other hand, Massa and Mayer (2006) could not replicate such an effect. The discrepancy between these findings might be a result of differences in defining visualizers and verbalizers in both studies, though. Massa and Mayer (2006) measured visual/verbal cognitive style as well as learning preference, while Plass et al. (1998) concentrated on learning preferences.

The inconsistencies of research results regarding advantages of instructional text and pictures for the learning of visualizers and verbalizers – and the predicted differences in processing information and learning outcomes between these groups – encouraged us to examine how visualizers and verbalizers learn from two different, in terms of topic and type of knowledge, combinations of pictures and texts.

4.1.3. Eye-Tracking and learning

Eye-Tracking research revealed that people differ in their patterns of reading a text. Generally, the most effective strategy is to pay special attention to topic sentences and topic-relevant information in the text (Hyönä et al., 2002). While dealing with stimuli containing text and pictures, research showed that learning is heavily driven by text (Hannus & Hyönä, 1999; Schmidt-Weigand et al., 2010), and that learners tend to spend more time looking at the text than at the pictures (Rayner et al., 2001). However, best learning outcomes can generally be achieved when information from pictures and texts is integrated.

The way of looking at a stimulus depends on its construction. Some studies showed, in line with the spatial contiguity principle (Mayer, 2014), that shorter physical distance between textual and pictorial information facilitates the integration of information from these two sources by finding correspondences between them (e.g., Holsanova et al., 2008). Especially a serial layout, that is a spatially structured, sequential format of the information materials, enhances the integration (Holsanova et al., 2008). The presence of more abstract illustrations, like decontextualized charts or diagrams, rather than concrete, more realistic ones in the learning material, is less demanding for working memory and therefore helps to process the text more efficiently and also promotes integration of information (Mason et al., 2013a). On the other hand, when readers interpret pictures and text as separate and self-contained, they tend to choose only one of them and ignore the other one (Holsanova, et al., 2008; Sweller et al., 1998).

Previous studies showed also that the way of gazing at the presented stimuli is strongly related to individual differences such as prior knowledge and intelligence. For example, Hannus and Hyönä (1999) showed that high-ability students spent more time gazing at relevant areas of stimuli than did low-ability students. They also returned to relevant areas of stimuli and switched between relevant parts of text and pictures more often than low-ability students. The latter spent more time gazing at irrelevant, blank spaces between and around texts and pictures (Hannus & Hyönä, 1999). The same effect was found in a study conducted by Jarodzka et al. (2010) in which experts and novices described fish´ locomotion. The former spent more time gazing at important parts of presented videos than the latter.

Several studies also suggested that cognitive style can have an influence on the way of looking at the stimuli. Mehigan et al. (2011) claim that it is possible to use eye-tracking technology for identifying visual/ verbal learners. In their study, they referred to the visual/ verbal dimension of the Felder-Silverman Learner Style Model (FSLSM), using for participants' selection the Felder-Solomon Index of Learning Styles (FSILS) questionnaire. Visual learners and verbal learners performed different patterns of gazing at pictorial and textual information while undertaking an e-learning task: Visual learners outperformed verbal learners in focusing on pictorial learning objects, while verbal learners spent more time on textual content than visual learners. The stronger the visual style of learning was, the more time the learners spent on pictorial content. Similar results were shown by Tsianos et al. (2009), who found that visualizers (or imagers, as the study referred to the verbal/ imager axis of Riding and Cheema`s Cognitive Style Analysis; Riding & Cheema, 1991) concentrated mostly on pictorial content, verbalizers on text, while intermediates were placed in between.

4.1.4. Objectives of the study

All in all, there is strong indication that the visualizer-verbalizer cognitive style has an influence on learning behavior. The question remains, however, if and how exactly verbal and visual learners differ in their way of learning from texts and pictures, and if these differences result in different learning outcomes. The main objective of the present study was therefore to further examine the differences between visualizers and verbalizers regarding their gaze behavior and their learning outcome when learning with text-picture combinations.

Our hypotheses are as follows:

(1) In line with findings of Mehigan et al. (2011) and Tsianos et al. (2009), visualizers will generally spend more time focusing on pictures than verbalizers, and verbalizers will generally spend more time focusing on texts than visualizers.

(2) Assuming that visualizers are – in a way – experts in using pictures, and referring to studies conducted by Hannus and Hyönä (1999) and Jarodzka et al. (2010), visualizers, similar to high-ability students, will be better at identifying relevant areas in pictures than verbalizers, which means that visualizers will enter relevant areas of pictures sooner than verbalizers. Verbalizers, similar to low-ability students, will enter the irrelevant areas of pictures sooner than visualizers.

(3) Assuming that both groups will use the best integrative way of learning (Mason et al., 2013b), but *within* those sources of information that correspond to their cognitive style, visualizers will shift their point of focus across pictures more frequently than verbalizers, and verbalizers will shift their point of focus across texts more frequently than visualizers.

(4) Visualizers profit from text-picture combinations more than verbalizers (Riding & Douglas, 1993; Höffler et al., 2010), and might be better in integrating information represented in both the verbal and visual channel (as described in the cognitive theory of multimedia learning), so they will achieve better learning outcomes on comprehension scales than verbalizers.

4.2. Method

4.2.1. Participants

University students of all majors between 20 and 29 years of age were invited to participate in the study – with the exception of physics, biology and psychology students, because of their too broad pre-knowledge on the presented topics of learning. About 90 prospective candidates were pre-classified as either verbalizers or visualizers on the basis of a telephone interview consisting of 14 yes/ no questions based on the Verbal-Visual Learning Style Rating questionnaire (VVLSR; Mayer & Massa, 2003), the Individual Differences Questionnaire (Paivio & Harshman, 1983), and the Santa Barbara Learning Style Questionnaire (SBCSQ; Mayer & Massa, 2003). Those individuals whose answers to the interview questionnaire did not allow us to clearly distinguish them as either visualizer or verbalizer were not invited to the study. 48 students with relatively clear visual or verbal orientations were selected for further individual testing. From these 48 participants, we had to exclude 16 participants from further analyses because of calibration problems and/ or deficient quality of the eye-tracking data. That left us with 32 participants (68.8% female, age $M = 24.63$; $SD = 2.31$ years).

4.2.2. Instruments and procedure

First, the participants filled in a set of questionnaires that included demographic questions and six questionnaires regarding the visualizer-verbalizer cognitive style (the Verbal-Visual Learning Style Rating, VVLSR, Mayer & Massa, 2003, one single item; the Individual Differences Questionnaire, visual scale, Paivio & Harshman, 1983, $\alpha = .93$; the Santa Barbara Learning Style Questionnaire, SBCSQ, Mayer & Massa, 2003, $\alpha = .92$; the Vividness of Visual Imagery Questionnaire, VVIQ, Marks, 1973, $\alpha = .94$; the Verbalizer-Visualizer Questionnaire, VVQ, Richardson, 1977, $\alpha = .77$; and the Object-Spatial Imagery and Verbal

Questionnaire, (OSIVQ), shortened version, Blazhenkova & Kozhevnikov, 2009, with three scales spatial, $\alpha = .86$, verbal, $\alpha = .79$, and object, $\alpha = .93$). This first part of the study lasted for about 25 minutes.

Second, participants answered questions measuring their prior knowledge of two topics to be presented, which were “functioning of a toilet cistern” and “learned helplessness”. These two contrasting topics were chosen to identify gaze patterns for different types of knowledge. The toilet cistern topic is an example of knowledge regarding functioning of mechanical systems. The learned helplessness topic illustrated the Seligman and Maier experiment on dogs (1967) and is an example of conceptual knowledge. For both topics, we expected participants to have low prior knowledge. To assess their prior knowledge we asked participants to answer open questions regarding each of these two topics. Interrater-agreements were 91.5 % (4 items) for the toilet cistern set and 97.3 % (4 items) for the learned helplessness set.

Third, for each of the two topics, participants were shown, on a 22 inch computer screen, a set of learning materials being composed of pictures with accompanying texts. While studying the learning materials, eye movements were measured with a SMI RED 120 Hz Eye Tracking system, offering the possibility of free head movements (40cm x 20cm at 70cm distance), accuracy of 0.4°, spatial resolution (RMS) of 0.03°, and sampling rate of 60Hz and 120Hz.

Fourth, a posttest including 12 yes/no and 2 open questions was administered. An example of a yes/no question was: “The first dog continued to stay helpless because it was conditioned to bear the electrical hits. True or false?”. An example of an open question was: “Please explain the meaning of the term ’learned helplessness’!”.

Reliabilities (Cronbach´s alpha) for the yes/ no questions were $\alpha = .75$ (6 items) for the toilet cistern set and $\alpha = .60$ (6 items) for the learned helplessness set. Interrater-agreements for open questions were 89.4 % (7 items) for the toilet cistern set and 83.5 % (6 items) for the learned helplessness set. The competent judges rated in open questions the level of comprehension, while the yes/ no questions indicated the level of retention.

4.2.3. Learning materials and Areas of Interest (AOIs)

While the learning material was self-developed, the toilet cistern topic was inspired by the work of Hegarty et al. (2003).We decided to present each topic to be learned in a series of three pictures and three boxes of related text (Figure 4.2).

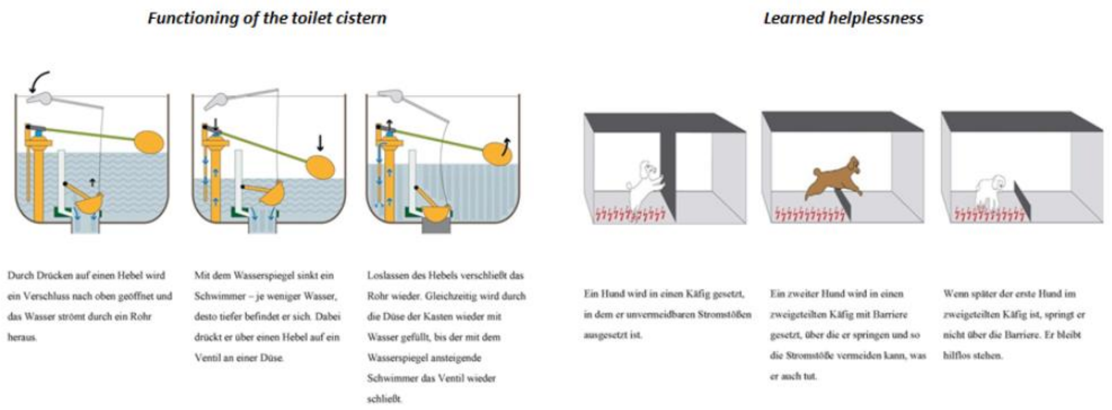

Figure 4.2. The two sets of learning materials (stimuli) used in the study.

Both sorts of information were placed near to each other (cf., Holsanova et al., 2008), and the pictures were designed in a rather abstract manner (Mason et al., 2013a) in order to facilitate the integration of knowledge. Both texts and pictures contained comparable information (i.e., were self-contained). The equivalence of text and picture contents was checked beforehand with a small sample of seven participants who were shown pictures or texts separately and asked to explain what they had learned from them. Furthermore, each set was designed in a comparable way (pictures above, texts below). The sets had different levels of difficulty. The learned-helplessness topic was consentaneously ranked as easier than the toilet-cistern set by seven participants of the pilot study. Therefore, the toilet-cistern set was presented for 2.5 minutes, and the much easier to understand learned-helplessness set was presented for only 1.5 minutes.

Each of the two sets of text-picture combinations was analyzed with respect to Areas of Interest (AOIs), that is, regions in the stimuli we were especially interested in. At first, for each set, we created AOIs representing texts and pictures, that is, three AOIs for the three texts, three AOIs for the three pictures, and six to eight AOIs for empty space around texts and pictures. For more detailed analyses, we created AOIs inside pictures, separating regions containing relevant areas from irrelevant ones. The relevant areas were defined with help of three experienced judges as those parts of pictures which were essential for understanding the depicted information and could not be omitted in order to understand it. The irrelevant areas were understood as those parts of pictures that provided no such information such as decorations or trimmings. For the textual parts, we did not define specific AOIs, as the eye-tracker was unfortunately not precise enough for such a detailed analysis within texts.

In analyzing the eye-tracking data, we focused on basic AOI events (according to Holmqvist et al., 2011), that means on such parameters as *entry time* (duration from start of the trial to the first hit of the AOI in ms), *dwell time* (sum of durations from all fixations and saccades that hit the AOI in ms), and *transitions* (movements from one AOI to another; see Holmqvist et al., 2011).

4.3. Results

As expected, participants, both verbalizers and visualizers, showed low prior knowledge on both learning topics and did not differ significantly (Table 4.1).

Table 4.1: Prior knowledge on the study topics

	Visualizers	Verbalizers				
Topic	*M (SD)*	*M (SD)*	*t*	*df*	*p*	Range*
Toilet cistern	0.31 (0.28)	0.20 (0.23)	1.21	30	.236^{ns}	0-1
Learned helplessness	0.06 (0.17)	0.02 (0.06)	1.03	18.95	.316^{ns}	0-1

*The range of points the participants could possibly receive on the scale.

As all hypotheses are in regard of the statistical interaction of cognitive style (representing a between-subjects factor) and specific aspects of learning behavior and learning outcome (representing within-subjects factors), repeated-measures analyses of variance (RM-ANOVA) were computed, using a multivariate approach. In all analyses it was tested whether the statistical interaction of cognitive style and learning behavior (or learning outcome) would differ with respect to the learning topic (toilet cistern versus learned helplessness) by calculating the triple interaction of cognitive style, learning behavior (or learning outcome), and learning topic. Note that we were not interested in determining any main effects of the learning topics as the two learning sets differed with regard to pre-defined learning time and instrumentation of learning outcome variables. Therefore, before calculating RM-ANOVAs, all dependent learning behavior variables (or learning outcome variables) representing levels of within-subjects factors in our analyses were linearly transformed to standardized (z) scores with $M = 0$ and $SD = 1$. The means and standard deviations of all transformed variables are given in the Appendix.

4.3.1. Hypothesis 1: Time focusing on pictures and texts

For illustrative purposes, two exemplary "heat maps" for the toilet cistern topic show the viewing patterns (in terms of the amount of fixations participants made in certain areas of the stimulus) of a typical verbalizer (Figure 4.3) and a typical visualizer (Figure 4.4). Red and yellow colors indicate many fixations, green and blue colors fewer fixations. It can easily be seen that there are huge differences between the two viewing patterns with the visualizer focusing on pictures and the verbalizer focusing on texts.

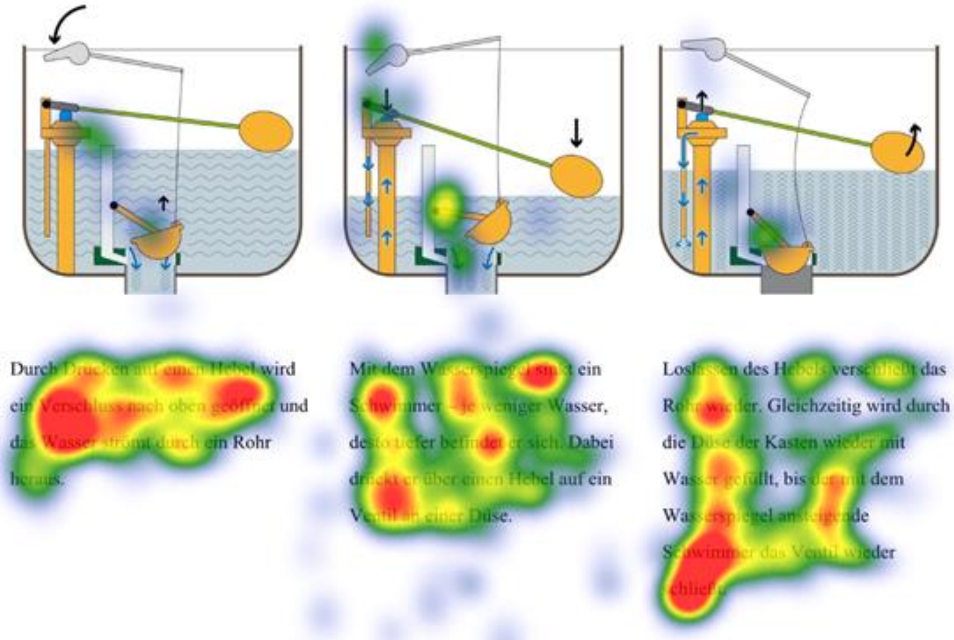

Figure 4.3. A heat map of a verbalizer.

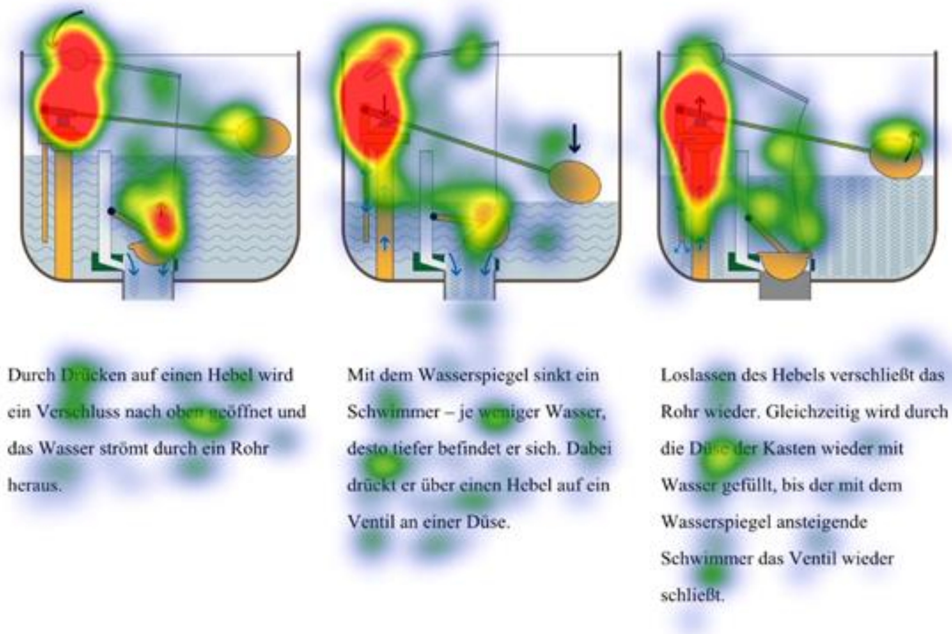

Figure 4.4. A heat map of a visualizer.

The first hypothesis states that (a) visualizers will generally spend more time focusing on pictures than verbalizers and that (b) verbalizers will generally spend more time focusing on texts than visualizers. In order to test this hypothesized interaction, we calculated a RM-ANOVA on dwell time with cognitive style (visualizer, verbalizer) as the between-subjects factor and area of interest (AOI: text, picture) and learning topic (toilet cistern, learned helplessness) as two completely crossed within-subjects factors. Results indicated the expected interaction of cognitive style and AOI, $F(1,30) = 19.45$, $p < .001$, $\eta^2 = .393$. All other effects in the linear model, including the triple interaction of cognitive style, AOI, and learning topic, were not statistically significant, all $F < 1$.

Figure 4.5 displays the interaction of cognitive style and AOI. As expected, visualizers ($M = 0.56$, $SD = 0.58$) spent more time focusing on pictures than verbalizers ($M = -0.56$, $SD = 0.83$), simple main effect $t(30) = 4.47$, $p < .001$, $d = 1.63$, whereas verbalizers ($M = 0.56$, $SD = 0.88$) spent more time focusing on texts than visualizers ($M = -0.56$, $SD = 0.56$), simple main effect $t(30) = 4.29$, $p < .001$, $d = 1.57$. The missing triple interaction indicates that this interaction pattern does not differ for the two learning sets.

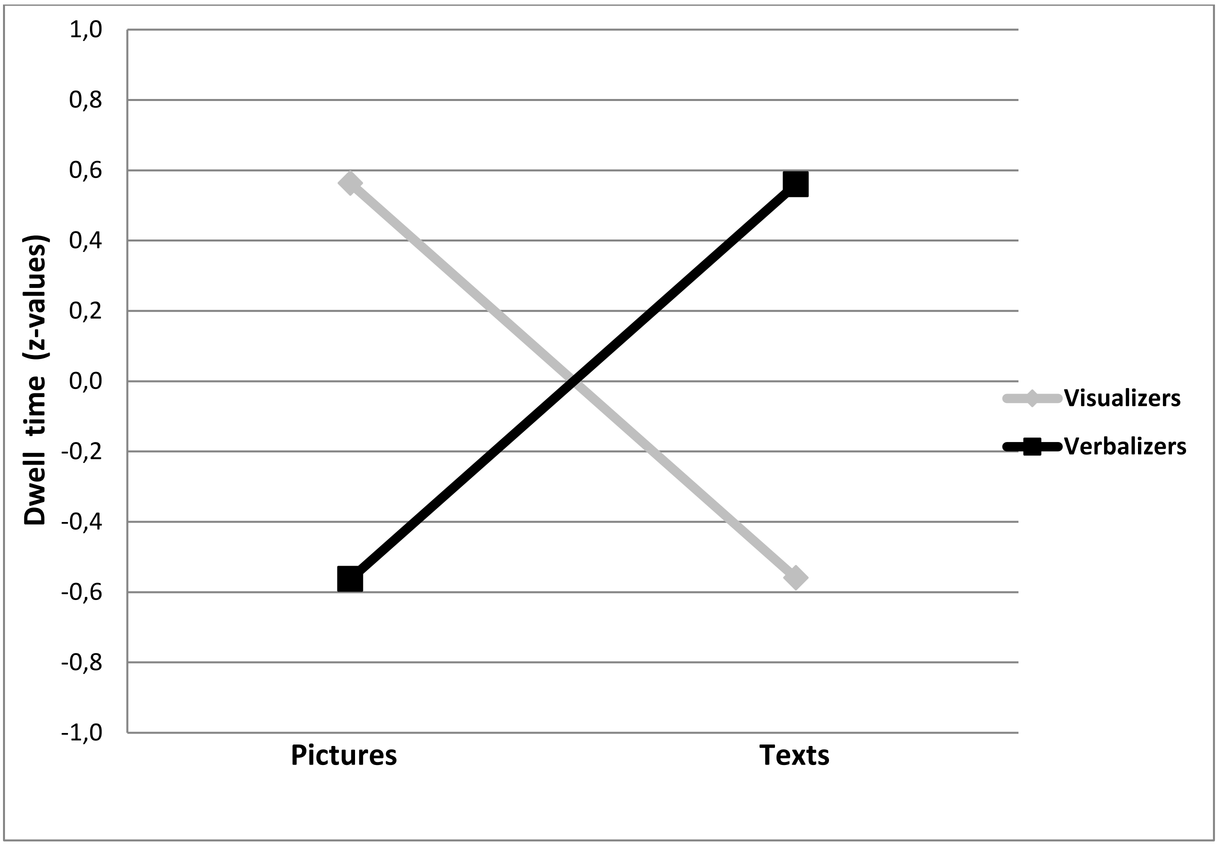

Figure 4.5. Dwell time (z-values) as a function of cognitive style.

4.3.2. Hypothesis 2: Identifying relevant areas in pictures

The second hypothesis states that (a) visualizers will enter relevant areas in pictures sooner than verbalizers, and that (b) verbalizers will enter the irrelevant areas of pictures sooner than visualizers. In order to test this hypothesized interaction, we calculated a RM-ANOVA on entry time with cognitive style (visualizer, verbalizer) as the between-subjects factor and AOI (irrelevant, relevant) and learning topic (toilet cistern, learned helplessness) as two completely crossed within-subjects factors. Results indicated the expected interaction of cognitive style and AOI, $F(1,30) = 7.26$, $p = .011$, $\eta^2 = .195$. All other effects in the linear model, including the triple interaction of cognitive style, AOI, and learning topic, were not statistically significant (all $p > .10$).

Figure 4.6 displays the interaction of cognitive style and AOI. In contradiction to our expectations, visualizers (*M* = -0.10, *SD* = 0.68) did not enter the relevant areas of pictures sooner than verbalizers (*M* = 0.10, *SD* = 0.77), the simple main effect was not significant, *t*(30) = 0.75, *p* =.462, *d* = .27. On the other hand, in line with our expectations, verbalizers (*M* = -0.34, *SD* = 0.80) entered the irrelevant areas of pictures sooner than visualizers (*M* = 0.34, *SD* =0.52), simple main effect *t*(30) = 2.83, *p* = .008, *d* = 1.03. The missing triple interaction indicates that this interaction pattern does not differ for the two learning sets.

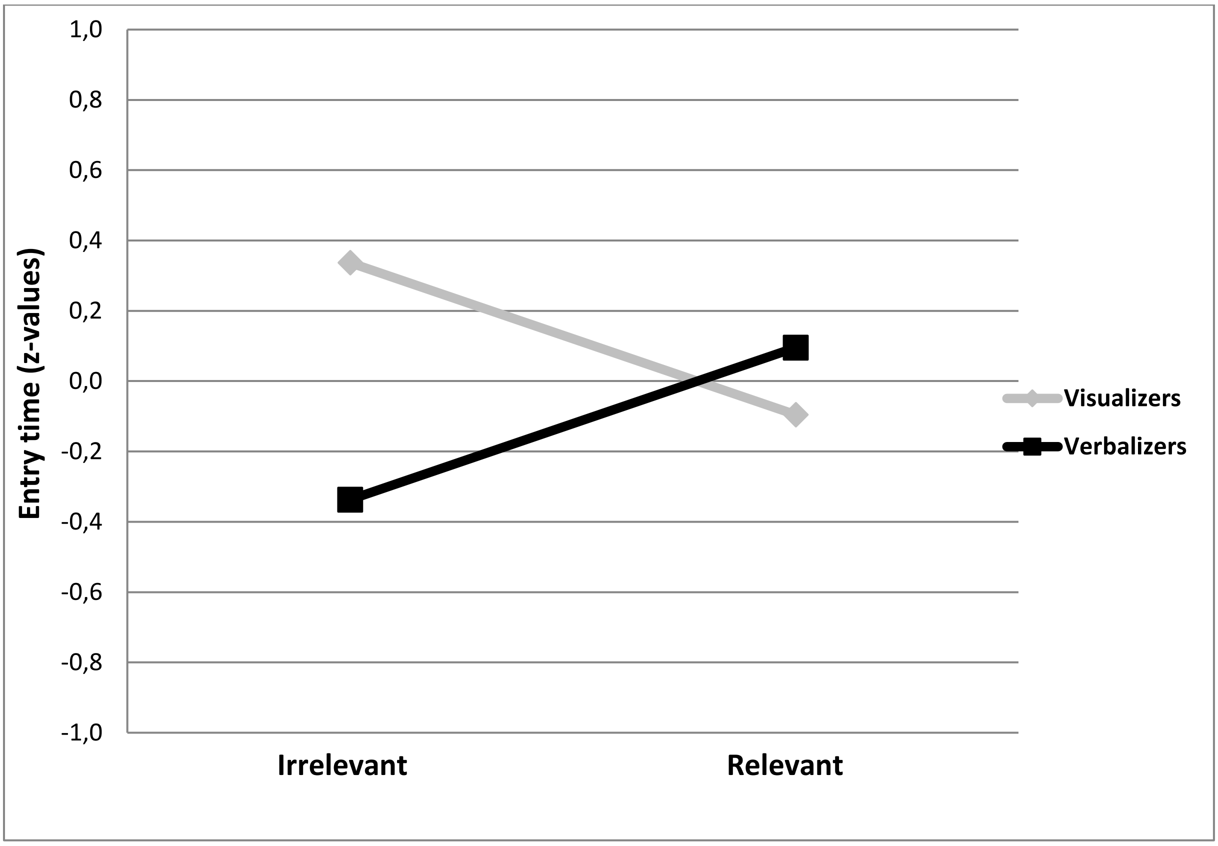

Figure 4.6. Entry time (z-values) as a function of cognitive style.

4.3.3. Hypothesis 3: Shifting the point of focus

The third hypothesis states that (a) visualizers will shift their point of focus from picture to picture more frequently than verbalizers, and that (b) verbalizers will shift their point of focus from text to text more frequently than visualizers.

In order to test this hypothesized interaction, we calculated a RM-ANOVA on number of transitions with cognitive style (visualizer, verbalizer) as the between-subjects factor, type of transitions (from picture to picture, from text to text), and learning topic (toilet cistern, learned helplessness) as two completely crossed within-subjects factors. Results indicated the expected interaction of cognitive style and AOI, $F(1,30) = 9.94$, $p = .004$, $\eta^2 = .249$. All other effects in the linear model, including the triple interaction of cognitive style, type of transitions, and learning topic, were not statistically significant (all $p > .20$).

Figure 4.7 displays the interaction of cognitive style and AOI. As expected, visualizers ($M = 0.36$, $SD = 0.83$) shifted their point of focus from picture to picture more frequently than verbalizers ($M = -0.36$, $SD = 0.68$), simple main effect $t(30) = 2.66$, $p = .012$, $d = .97$, whereas verbalizers ($M = 0.38$, $SD = 1.11$) shifted their point of focus from text to text more frequently than visualizers ($M = -0.38$, $SD = 0.44$), simple main effect $t(19.57) = 2.54$, $p = .020$, $d = .93$. The missing triple interaction indicates that this interaction pattern does not differ for the two learning sets.

Additionally, we tested whether there is a difference between visualizers and verbalizers concerning shifting the point of focus from picture to text or vice versa. This difference, however, was not significant, $t(30) < 1$.

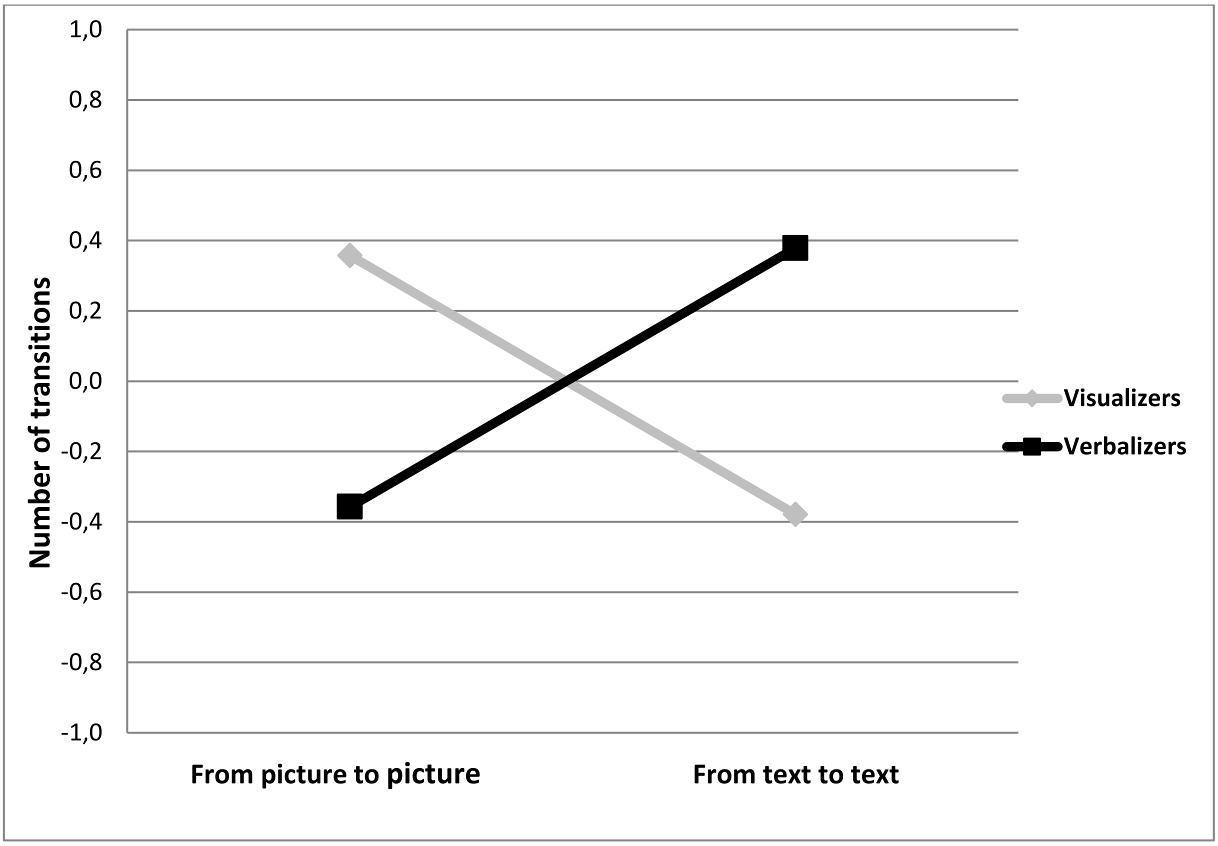

Figure 4.7. Number of transitions (z-values) as a function of cognitive style.

4.3.4. Hypothesis 4: Learning outcome

The fourth hypothesis states that visualizers will achieve better learning outcomes on comprehension scales than verbalizers. In order to test this hypothesized interaction, we calculated a RM-ANOVA on learning outcome with cognitive style (visualizer, verbalizer) as the between-subjects factor and type of learning outcome (retention, comprehension) and learning topic (toilet cistern, learned helplessness) as two completely crossed within-subjects factors. Results indicated the expected interaction of cognitive style and type of learning outcome, $F(1,30) = 4.71$, $p = .038$, $\eta^2 = .136$. All other effects in the linear model, including the triple interaction of cognitive style, AOI, and learning topic, were not statistically significant (all $p > .05$).

Figure 4.8 displays the interaction of cognitive style and type of learning outcome. As expected, visualizers (M = 0.32, SD = 0.64) outperformed verbalizers (M = -0.32, SD = 0.65) on comprehension, simple main effect $t(30) = 2.85$, $p = .008$, $d = 1.04$. There was no significant difference between visualizers and verbalizers, however, on retention, simple main effect $t(30) = 0.49$, $p = .626$, $d = .18$. The missing triple interaction indicates that this interaction pattern does not differ for the two learning sets.

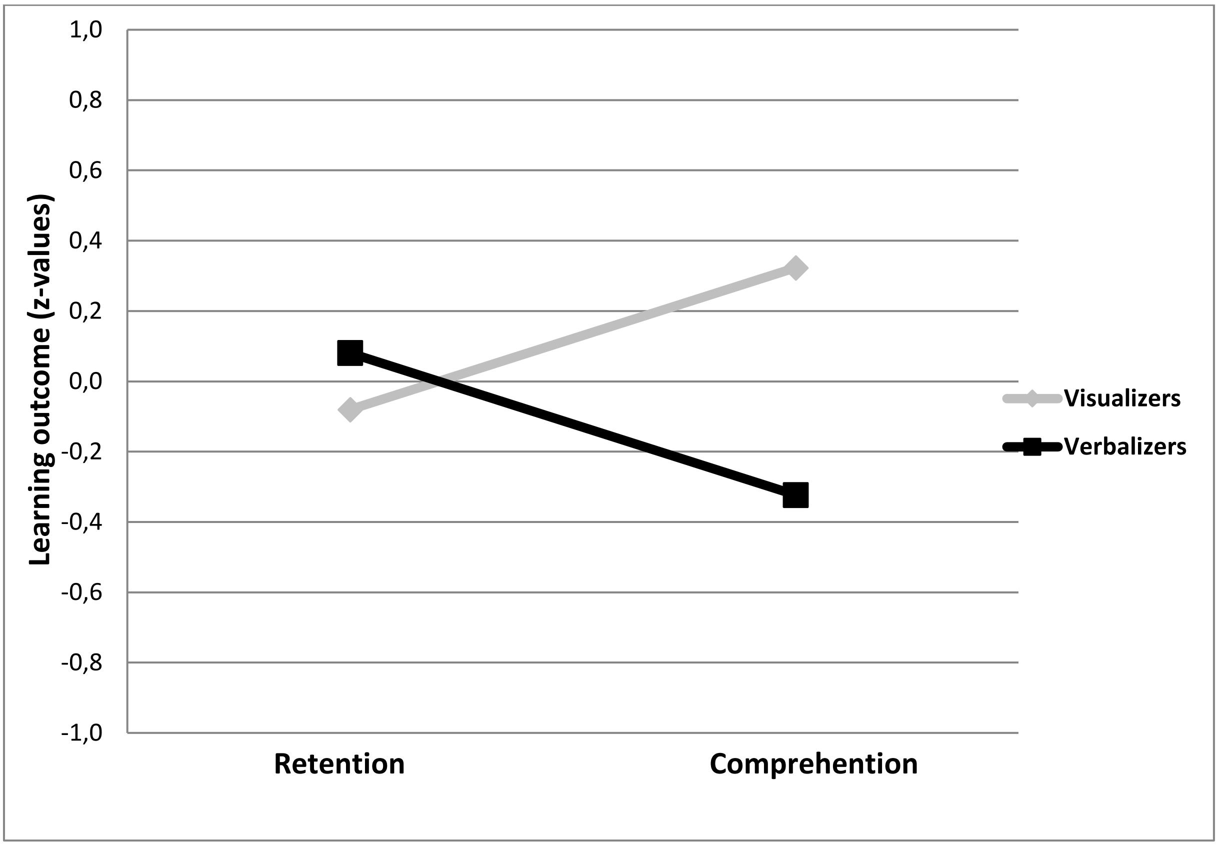

Figure 4.8. Learning outcome (z-values) as a function of cognitive style.

4.4. Discussion

In the present study we confirmed that people, classified according to their visualizer-verbalizer cognitive style, differ in their learning behavior in terms of using pictorial and verbal information while learning. When confronted with information that is comparable in terms of content and presented to them in texts and in pictures, verbalizers tend to rely on verbal information and visualizers tend to rely on pictorial information (see also Mehigan et al., 2011; similarly Tsianos et al., 2009), regardless of the type of knowledge (e.g., conceptual knowledge vs. knowledge regarding functioning of a mechanical system) the topic provides and its level of difficulty. Our results strongly support not only the existence of the visual-verbal cognitive style but also its influence on learning behavior.

Having in mind that many studies showed learning to be heavily driven by text (Hannus & Hyönä, 1999; Schmidt-Weigand et al., 2010) and that students generally prefer to look at text rather than at pictures while learning (Rayner et al., 2001), our results indicate that visualizers seem to contradict this typical text-oriented way of learning: Concerning the patterns of eye movements in our study, visualizers showed a strong picture-oriented way of learning rather clearly. Verbalizers, on the other hand, not only spent less time on the pictures than visualizers but also tended to enter irrelevant parts of pictures sooner than verbalizers. Visualizers tended to switch to irrelevant parts of stimuli later. These observations partly support our assumption that visualizers are kind of “experts” on pictures (at the same time, verbalizers seem to be experts on texts) which is in line with findings of Hannus and Hyönä (1999) with high-ability and low-ability students, and those of Jarodzka et al. (2010) with experts and novices, in that visualizers, comparably to high-ability students and experts, seem to concentrate on the relevant areas of pictures while learning (even though they did not have a higher prior knowledge).

The ability to use pictures in a more efficient way can have some profits. In our study, learning outcomes regarding comprehension were higher in visualizers than in verbalizers. This result is even more interesting when we consider that both groups displayed an active way of learning, manifested by the number of transitions, but within their preferred mode of information (pictures for visualizers and texts for verbalizers). We might state that both groups invested comparable mental effort in order to understand the topic, but on different Areas of Interest. We did not observe differences between both groups in the number of transitions between pictures and texts. Further research is needed to figure out whether “understanding” pictures is crucial to achieve good learning outcomes or whether visualizers processed information from pictures in a way that allowed them to retrieve more useful information,

The lack of differences between both groups of participants in terms of the number of text-to-picture and picture-to-text transitions also confirms that the learning material was self-contained, so participants could freely choose the source of information they prefer.

4.4.1. Limitations

Our study has some obvious limitations. While interpreting the results we need to remember that the visualizer-verbalizer cognitive style is a dimension. Most people display both styles (visual and verbal) to some extent. Strong visual or verbal cognitive style (especially verbal cognitive style; cf. Cao & Nishihara, 2012) is rather rare; hence the participants of our study, as people with high levels of either visual or verbal cognitive style, represent a selected group, which restricts our findings to this group only. One might even interpret their strongly manifested visual or verbal cognitive style as a kind of learning disorder, as they did not seem to be able to connect pictorial and textual material adequately.

On the other hand, our results do not differ for the two learning sets, in spite of their diversity in terms of content and difficulty, which speaks for a high external validity of our results.

Furthermore, unlike pictures, we could not establish relevant and irrelevant parts of stimuli in the text sections of our learning materials, as the eye tracker was not precise enough for such a fine-grained differentiation between textual parts. Further research is needed to enable more precise conclusions about visualizers' and verbalizers' learning behavior concerning text-based information.

4.4.2. Conclusions

Our results can be considered as an additional indication that individual differences in visualizer-verbalizer cognitive style do exist (Pashler, McDaniel, Rohrer, & Bjork, 2009). They can be observed in eye movements (Mehigan et al., 2011; Tsianos et al., 2009) and, thus, have a considerable influence on learning behavior, and on learning outcome (cf. Massa & Mayer, 2006; Rogowsky, Calhoun, & Tallal, 2015).

The present study can thus be regarded as a first step towards examining the actual learning behavior of visualizers and verbalizers. However, further research on the influence of the visualizer-verbalizer cognitive style on learning with multimedia using eye-tracking data is highly recommended; especially with randomly chosen participants rather than participants with high levels of either visual or verbal cognitive style.

Further studies might also want to investigate how verbalizers learn from pictures only and how visualizers learn from text only. It would be interesting to conduct a study with more systematic variations of layout and source of information, providing information, for example, exclusively with text or pictures. Does the lack of the preferred type of representation impair the learning effect (e.g., Plass et al., 1998)? This question, among others, still has no clear answer.

In the end, casting more light on the way in which visualizers and verbalizers use pictorial and verbal information will hopefully provide valuable input to teaching, learning, and the design of learning materials including e-learning as well as text books in schools.

Acknowledgements

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CHAPTER 5

DOES MODALITY PLAY A ROLE? VISUAL-VERBAL COGNITIVE STYLE AND LEARNING WITH STATIC PICTURES VERSUS ANIMATIONS

Abstract: The study presented in this paper aimed to examine the effect of visual and verbal cognitive style on learning with static pictures and animations. Learning materials in form of either computer-based animation or a series of static pictures with written or spoken explanatory text was presented to 197 students. We received a modality effect as the versions with spoken text provided better results on learning outcome than the versions with written text regardless of the intensity of visual cognitive style. Highly developed visualizers better learned from static pictures with written text than when confronted with an animation and written text. For learners with less developed visual cognitive style it was the other way around. No significant interaction effects were found regarding verbal cognitive style.

Keywords: cognitive style; verbalizer; visualizer; modality effect; ability-as-compensator effect

Koć-Januchta, M., Höffler, T. N., Eckhardt, M., & Leutner, D. (submitted). Does modality play a role? Visual-verbal cognitive style and learning with static pictures versus animations.

Learning using combinations of pictures and texts has been a subject of intense research for many years (e.g., Carney & Levin, 2002; Hegarty et al., 1996; Mayer, 1997). Even if there is a general beneficial influence of learning from texts and pictures, there are still many open questions regarding such issues as the type of picture-text combination (animated vs. non-animated) or the learners' characteristics. For example, some evidence suggests that animations seem to be a better learning environment than static pictures (e.g., Höffler & Leutner, 2007). Other studies have not focused on the question *what is better* (animations or static pictures) but *under which circumstances* the learning environment works better (e.g., ChanLin, 2001; Höffler & Leutner, 2011; Huk, 2006; Kalyuga, 2008). To this effect, a great range of individual learner characteristics has been investigated, among them general ability measures (Snow, 1989), spatial ability (Höffler & Leutner, 2011; Huk, 2006), and visual-verbal cognitive style (Massa & Mayer, 2006). Although the research results are often inconsistent (e.g., Kirschner & van Merriënboer, 2013; Massa & Mayer, 2006), the statement that different individual characteristics can have an impact on how people learn is still an obvious one. Thus, our study can be regarded as part of this research, focusing on the visual-verbal dimension of cognitive style. We hope to shed some light on the possible impact of different visual-verbal cognitive styles on learning outcome when learning with different visualizations (animations or static pictures) and with different modalities of the accompanying explanatory text (written or spoken). Our concern relates especially to the question whether one of the two hypotheses, the ability-as-enhancer hypothesis or the ability-as-compensator hypothesis, is more adequate (cf. Höffler & Leutner, 2011; Huk, 2006).

5.1. Theoretical background

5.1.1. Visual-verbal dimension of cognitive information processing

The visual-verbal dimension of cognitive information processing derives from dual-coding theory (Paivio, 1986) and states that information is processed and mentally represented along distinct channels: visual and verbal. Both mental representations are used when selecting, organizing, integrating, storing and retrieving information.

A growing body of evidence shows that some people prefer the verbal channel (verbal learners), while others prefer the visual channel (visual learners) when processing the information (e.g., Jonassen & Grabowski, 1993; Mayer & Massa, 2003). Mayer and Massa (2003) classified people in two groups according to their preferred modus of information representation – as either visualizers or verbalizers. There is great inconsistency in the literature though whether the visual-verbal dimension should be understood as cognitive style (e.g., Richardson, 1977), as learning preference (e.g., Leutner & Plass, 1998; Plass et al., 1998), or as learning style (e.g., Kirby et al., 1988). A factor analysis performed by Mayer and Massa (2003) on 14 measures resulted in the identification of four separate factors: cognitive style, learning preferences, spatial ability, and general achievement. Three of these factors referred to the visual-verbal dimension of information processing, namely cognitive style, learning preferences, and spatial ability. Mayer and Massa (2003) defined spatial ability as a type of cognitive ability, learning preferences as a tendency to choose pictures or texts when learning, and cognitive style as a way of thinking – either more in words or in pictures. According to this distinction, and in line with Messick's (1984) definition of a cognitive style as an individual manner of organizing and processing information, the current study refers to the visual-verbal dimension as a cognitive style. We aimed to compare learners with verbal or visual cognitive style when learning with different types of visualizations.

5.1.2. Multimedia learning

The term *multimedia learning* can be defined as such learning situations where information is presented to a student in more than one mode, e.g., visually and verbally (Mayer, 1997). According to the *multimedia principle* (Fletcher & Tobias, 2005), combining words and pictures in learning materials promotes comprehension and results in better learning outcomes than learning from words alone. The multimedia principle is supported by many empirical studies (e.g., Carney & Levin, 2002; Hegarty et al., 1996; Mayer, 1997). The beneficial impact of the pictorial-textual combinations on learning outcome is the result of activating both the verbal and the visual channel (Paivio, 1986) for processing the information and, eventually, evoking cognitive processes responsible for active learning (Fletcher, & Tobias, 2005).

The question is thus not if pictures and texts result in better learning outcomes, but under what circumstances. For example, picture-text combinations improve learning when the topic is difficult rather than easy (Carney & Levin, 2002). Mayer (2008) listed further principles for learning with multimedia among which we considered in our study especially the spatial contiguity principle (when texts and pictures are presented close to each other), the temporal contiguity principle (when texts and pictures are presented at the same time) and the modality principle (when animated pictures are provided with a spoken narration rather than a written text).

The effectiveness of learning with picture-text combinations is also strongly influenced by individual differences (e.g., Hegarty & Kriz, 2008). Such traits like spatial ability (Höffler & Leutner, 2011; Huk, 2006) or prior knowledge (ChanLin, 2001; Kalyuga, 2008) have a moderating effect on learning with pictures and texts. We might say that both features of the learning materials as well as individual differences of the learners have an influence on learning outcome.

5.1.3. Individual differences in learning with static pictures and animations

Mayer's (2008) cognitive theory of multimedia learning, which we refer to in our study, does not explicitly differentiate between different types of pictorial representation, namely, static pictures and animations. The results of a meta-analysis (Höffler & Leutner, 2007) show though that the impact of these two types of pictorial representations on learning outcome is not the same and should be studied separately. Animations, according to this meta-analysis, have the potential to contribute to better learning outcome than static pictures (overall mean effect size d=0.37). On the other hand, there are reports suggesting otherwise. In a study conducted by Mayer et al. (2005), for example, participants learning from static illustrations with printed text outperformed participants learning from animation and narration on retention and transfer tests. This result supports the hypothesis that static pictures minimize extraneous processing and support germane processing (Mayer et al., 2005). Animations, it seems, are not necessarily better learning materials (e.g., Tversky et al., 2002) and may enhance cognitive load (Hegarty, 2004).

Research regarding visual-verbal cognitive style leaves us with more questions than answers. When and under which circumstances are animations superior to static pictures? When is the opposite true? One answer is the ability-as-enhancer hypothesis, which states that a high level of ability enhances benefiting from a good instructional design (Huk, 2006). Figure 5.1 shows an exemplary ability-as-enhancer effect. In a study reported by Huk (2006) when learning from three-dimensional models students with high spatial ability outperformed students with low spatial ability. The latter were too cognitively overloaded to benefit from such a learning environment.

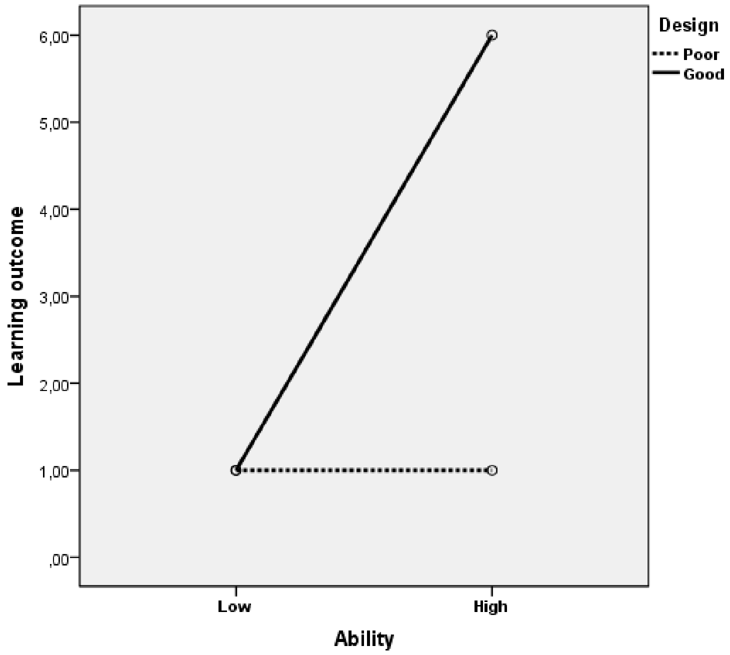

Figure 5.1. An exemplary model of an ability-as-enhancer effect.

According to an ability-as-compensator hypothesis (see Figure 5.2), a high level of ability enables benefiting from a poor instructional design (Höffler & Leutner, 2011).

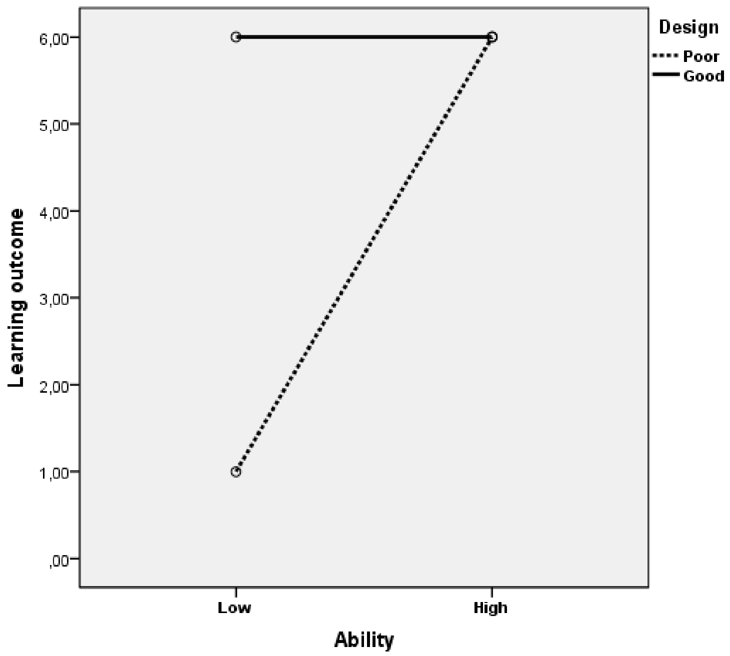

Figure 5.2. An exemplary model of an ability-as-compensator effect.

In a study of Höffler and Leutner (2011) low-spatial ability students and high-spatial ability students learned comparatively well when learning with animations, but significant differences between both groups were visible when learning with static pictures. In the latter condition low-spatial ability students performed poorer than high-spatial ability students because a high level of spatial ability compensated the limitations of a “worse” learning environment, that is, static pictures.

The results on prior knowledge as an individual differences variable in multimedia learning are also not consistent. In Kalyuga’s (2008) study, novices with low prior knowledge learned better from static pictures, while learners with high prior knowledge benefited more from animations. Yet, ChanLin (2001) showed that more experienced students learned comparably well from animations, static pictures and text, while novices learned better with static pictures.

The question which hypothesis – ability-as-enhancer or ability-as-compensator– is more plausible when studying visual-verbal cognitive style and its impact on learning outcome in multimedia learning has also not been solved yet. In a study by Höffler et al. (2010), highly developed visualizers learned better with static pictures than with animations, while less developed visualizers achieved comparable results both with animations and static pictures. On the whole, however, less developed visualizers performed worse on a learning outcome test than highly developed visualizers. These results partly support the ability-as-compensator hypothesis as highly developed visualizers performed better in the static pictures condition (a more difficult learning design or a “poorer” design). However, the pattern of results in the Höffler et al. study (2010) does not fully follow the pattern of the ability-as-compensator effect, as, contradictory to expectations, highly developed visualizers performed worse with animations than with static pictures on deeper comprehension. This last result connotes an expertise reversal effect which occurs when more experienced learners, learning from instructional material more suitable for novices are hindered from optimal performance (Kalyuga, 2007). Höffler et al.'s (2010) results are somewhat analog to this effect as a highly developed visual style helped to better learn from static pictures (more difficult learning design) but hindered somewhat when learning with animations (simpler learning design). A similar inhibiting effect among learners was reported by Schnotz and Rasch (2005). In their study, learners with higher prior knowledge did not benefit from the facilitating function of animation because the external support it provided kept the learners from performing cognitive processing on their own. In this case learners were provided with unrequired help which hindered their processing of information. In the study of Höffler et al. (2010) this "facilitation-hindrance" of animations occurred only among highly developed visualizers, not among less developed visualizers, which may suggest that highly developed visualizers act similarly to learners with higher prior knowledge (cf. Schnotz & Rasch, 2005). Höffler and Schwartz (2011), however, found different results. In their study, learners tending toward a visual cognitive style performed better on a learning outcome test when learning from animations, while learners tending toward a verbal cognitive style performed better when learning from static pictures. Chen and Sun (2012) found similar effects in which dynamic multimedia materials were better than static materials for visualizers.

Thus, the question regarding visual-verbal cognitive style and its influence on learning outcome when learning with animations and static pictures is still unanswered. Our study addresses the following research questions:

- Can we replicate the modality effect, that is, do learners learn better with spoken words rather than with written text when leaning with verbal and pictorial material (which is in line with Mayer, 2008)?

- Do we find an ability-as-compensator effect or rather an ability-as-enhancer effect regarding different learning outcomes for animations and static pictures dependent on learners' visual cognitive style?
- Will the same effect appear with verbal cognitive style?
- As the study of Höffler et al. (2010) was designed with written explanatory text only, we aimed to investigate whether the partial compensatory effect from this study is moderated by the presentation modality of the verbal explanation (written text versus spoken words). That is, in terms of learning outcome, does cognitive style, interact not only with the type of visualization but also with the type of modality? We expect differences regarding learning outcome especially in the written-text condition, as this condition should be more demanding for learners due to an overload of the visual information processing channel (cf. Paivio, 1986; Mayer, 2008).
- Will we receive an expertise reversal effect (Kalyuga, 2007) in the group of visualizers learning from animations?

5.2. Method

5.2.1. Participants

Participants were 197 students, mainly biology majors from Kiel University, mostly female (74.1%) and between 18 and 35 years of age (*M* = 21.68; *SD* = 2.40).

5.2.2. Learning environments

Four different versions of a computer-based learning environment were developed – two versions with animations (with written or spoken explaining text) and two versions with static pictures (with written or spoken explaining text). The topic was the primary reactions in photosynthesis (see Figure 5.3). Each version of the learning environment lasted 10 minutes and provided the same information. In the static-pictures versions, motions and movements were depicted by arrows. The explaining text / narration was identical in all versions. The learning environment was tested beforehand with a group of 30 biology students. This pretest helped us to determine that the learning material should be demonstrated twice in order to get better learning outcomes and to choose 20 well-differentiating posttest questions. The learning environment was non-interactive by design – participants did not have opportunity to stop or to fast-forward/ rewind the learning environment.

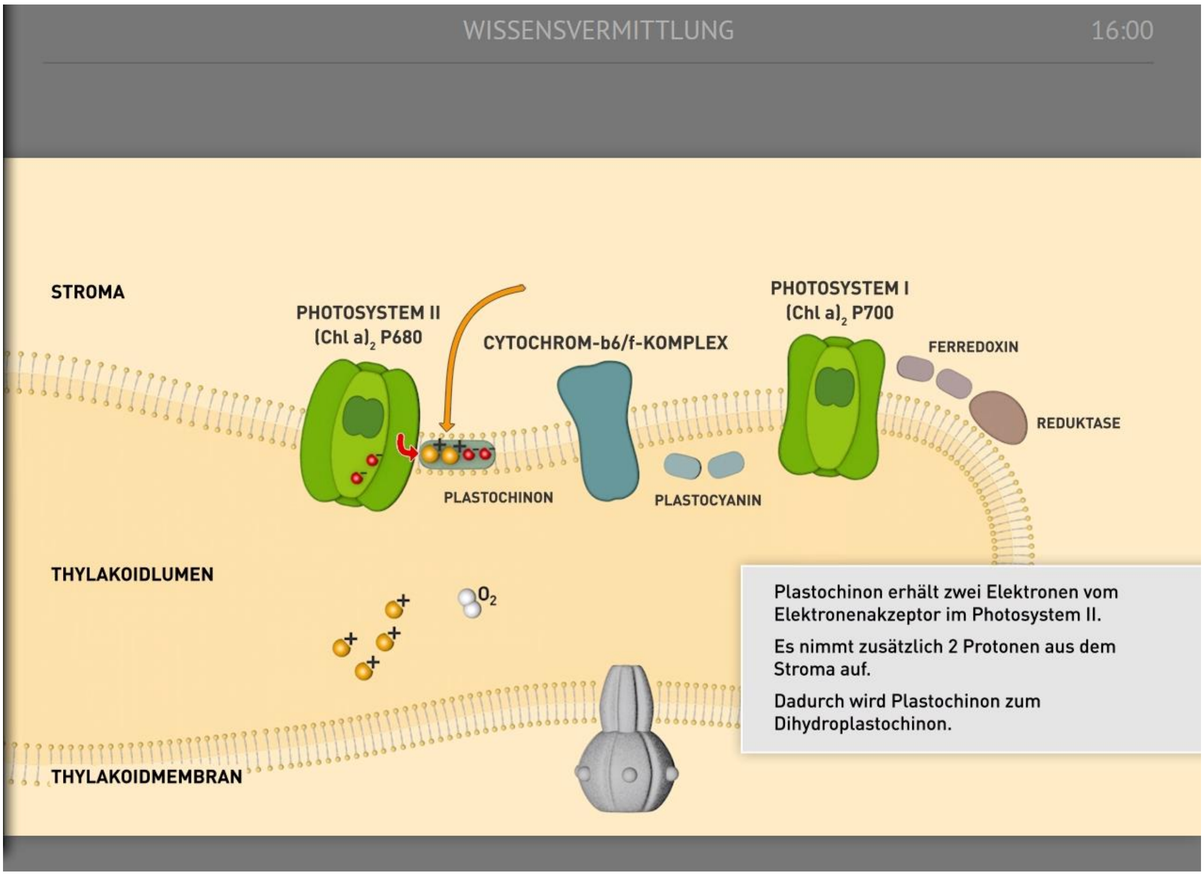

Figure 5.3. Exemplary snapshot of a static picture with written text. The text says: “Plastoquinone receives two electrons from electron acceptor in photosystem II. Additionally, it uptakes two protons from the stroma. As a result plastoquinone turns into dihydro-plastoquinone”.

5.2.3. Measures and instruments

Visual-verbal cognitive style was measured with two questionnaires:

- Individual Differences Questionnaire, IDQ (Paivio & Harshman, 1983; 2 scales: visual scale, α = .82; verbal scale, α = .82),
- Verbalizer-Visualizer Questionnaire, VVQ (Richardson, 1977; 2 scales: visual scale, α = .67; verbal scale, α = .74).

Prior knowledge about the topic was measured using three questions (one open question and two closed questions). The open question was rated by three independent raters. When they disagreed, a fourth rater decided. Learning outcome was measured with 20 closed questions (α = .70). Examples of questions measuring prior knowledge and learning outcome are shown in Table 5.1.

Table 5.1: Exemplary items for assessing prior knowledge and learning outcome.

	Exemplary item	Possible answers
Prior knowledge	Describe as closely as possible what happens during the primary reactions of photosynthesis.	Open question. Max. 8 points.
Prior knowledge	The products of the primary reactions of photosynthesis are:	a) Oxygen, ATP, NADPH+H+ b) Glucose and water c) Carbon dioxide and oxygen d) NADP+ and ADP
Learning outcome	During the primary reactions of photosynthesis water delivers its electrons directly to:	a) Photosystem I b) Photosystem II c) Carbon dioxide d) NADP+
Learning outcome	In order to destroy the weeds in his garden, a gardener used the DCMU herbicide. This compound prevents electron transfer to plastoquinone. Consequences are the following:	a) NADPH+H+ is still being constructed, the proton gradient is being raised, the ATP synthesis comes to a standstill b) The water splitting in the Photosystem II stops, NADPH+H+ and ATP are still being generated c) NADPH+H+ is not being generated anymore, no more protons are being pumped to the cytochrome b_6f complex, ATP is not being generated anymore d) The water splitting in the Photosystem II is still on, the proton gradient is being raised, ATP is being generated.

5.2.4. Procedure

At first, participants answered several questions regarding their age, sex, semester, university major, and GPA in high school (Abitur). Next they completed the two questionnaires regarding visual-verbal cognitive style (IDQ, VVQ). After answering three prior knowledge questions, they watched the learning environment twice (20 min). Participants were randomly assigned to one of four conditions (versions). At the end of the study, participants answered 20 posttest questions. The whole study was computer-based and lasted for about one hour.

5.3. Results

As expected, participants had little prior knowledge on the topic (M = 1.18, SD = 1.34, with 10 as the possible maximum). In order to differentiate between visualizers and verbalizers, we performed a principal component analysis (oblimin rotation) on the four cognitive style scales scores (two visual scales and two verbal scales). As expected, the analysis showed that the scales loaded on two factors, a visual and a verbal one (variance accounted for: 79%). We used the two factor scores as indicators of the intensity of visual and verbal cognitive style.

We analyzed the data within the framework of the General Linear Model (Horton, 1978) with a sequential decomposition of variance, performing analyses for the dependent measure of learning outcome represented as percentage of correct answers. Treatment factors were type of modality (written text versus spoken text) and type of visualization (static pictures versus animation). Cognitive style and GPA (from high school) were covariates. Analyses were separately conducted for visual cognitive style and verbal cognitive style as a covariate. In each analysis the variance of the dependent variable was decomposed by taking the predictors in the following sequence into the linear model: (1) the covariates, (2) the treatment factors and their interaction, (3) the two interactions of cognitive style and each of the treatment factors, and (4) the triple interaction of cognitive style and the two treatment factors. We expected this triple interaction of cognitive style, type of modality, and type of visualization to be statistically significant indicating that the effect of the treatments is moderated by cognitive style.

5.3.1. Visual cognitive style

In the analysis with visual cognitive style as the covariate, we received the expected modality effect, $F(1,185) = 3.60$, p (one-tailed, 1-*df*-test) = .059/2 = .030, η^2=.019; M_{spoken} = 64.65; SD_{spoken} = 15.15; M_{written} = 60.05; SD_{written} = 18.05. We received the expected triple interaction of visual cognitive style, type of modality, and type of visualization as well, $F(1,185) = 3.93$, $p = .049$, η^2=.021. Table 5.2 shows the results of all effects of this analysis, and Figure 5.4 displays the significant triple interaction.

Table 5.2: Results of the analysis with visual cognitive style.

Effect	F	df	p	η^2
GPA (school)	2.95	1,185	.088	.016
Visual cognitive style	1.60	1,185	.208	.009
Type of modality	3.60	1,185	.059	.019
Type of visualization	1.62	1,185	.205	.009
Type of modality X type of visualization	0.33	1,185	.564	.002
Visual cognitive style X type of modality	0.03	1,185	.869	.000
Visual cognitive style X type of visualization	2.96	1,185	.087	.016
Visual cognitive style X type of modality X type of visualization	3.93	1,185	.049	.021

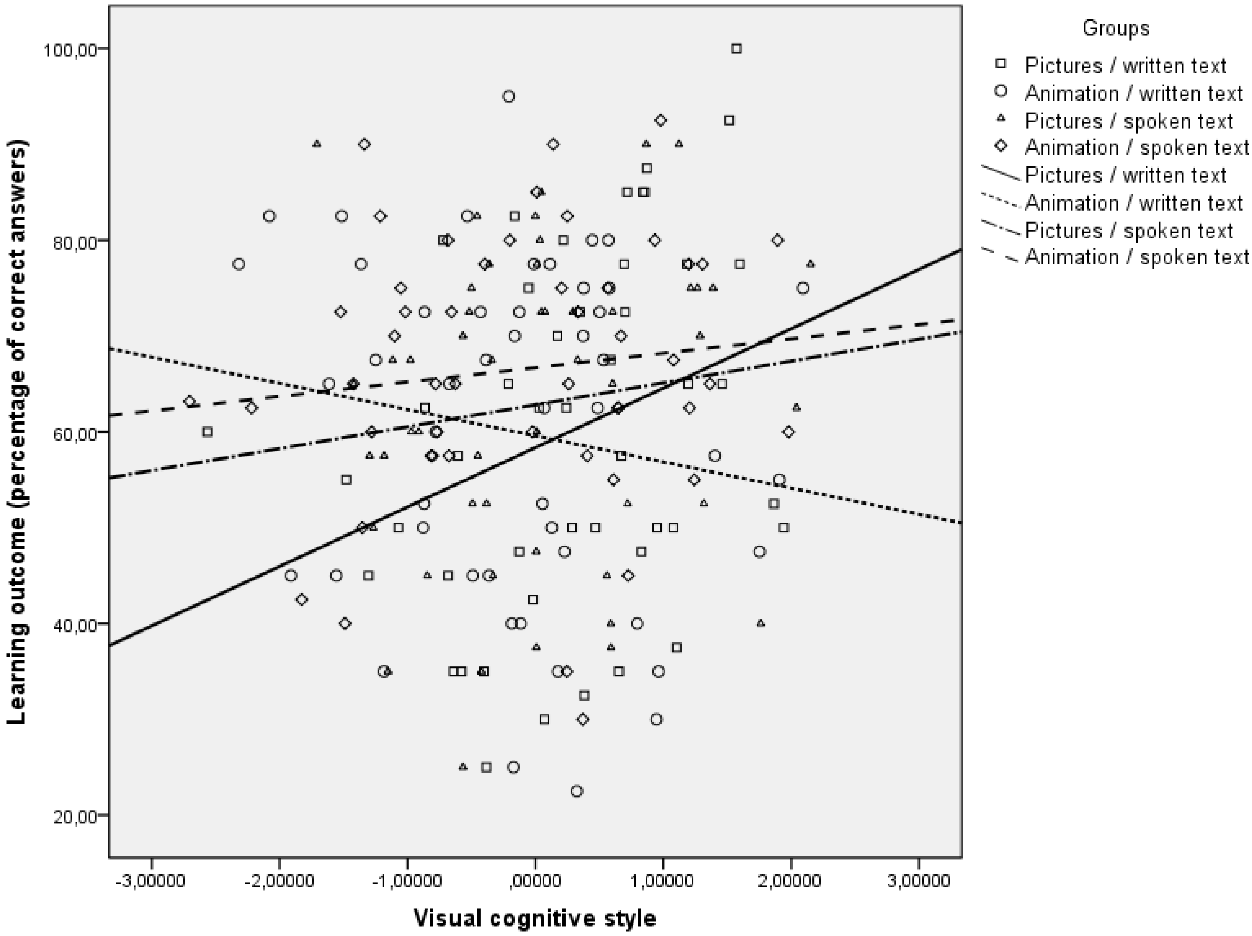

Figure 5.4. Learning outcome (percentage of correct answers) as a function of visual cognitive style, type of visualization and type of modality.

As can be derived from Figure 5.4, a higher visual cognitive style comes along with better learning outcomes with static *pictures accompanied by written text.* On the other hand, higher visual cognitive style comes along with poorer learning outcomes with *animations accompanied by written text*. For lower visual cognitive style, the opposite is true. Interestingly, visual cognitive style seems to make no difference when learning with either animations or static pictures with *spoken text*. Or, in other words, visual cognitive style correlates positively with learning outcome when learning with *written* text to explain pictures (r = .34, controlling for high-school GPA). This correlation is reduced when learning with *spoken* text to explain pictures as well as the animation (r = .09 and r = .14, respectively) and turns to the weak negative side when learning with *written* text to explain an animation (r = -.15). Thus, this first analysis indicates the expected modality effect (learning with spoken text outperforms learning with written text). Furthermore, this analysis indicates that, in the written text condition, learning outcome depends on visual cognitive style with a medium positive correlation for the pictures condition and a weak negative correlation for the animation condition.

5.3.2. Verbal cognitive style

In an analysis with verbal cognitive style as the covariate we received the expected modality effect, $F(1,185) = 2.92$, p (one-tailed, 1-df-test) = .089/2 = .045, η^2=.016; M_{spoken} = 64.65; SD_{spoken} = 15.15; M_{written} = 60.05; SD_{written} = 18.05. We did not receive any other significant interaction effects in the comparable analyses with verbal cognitive style (and GPA) as covariates (all p > .05). The results of all effects of these analyses are given in Table 5.3.

Table 5.3: Results of the analysis with verbal cognitive style.

Effect	F	df	p	η^2
GPA (from school)	2.86	1,185	.093	.015
Verbal cognitive style	0.63	1,185	.430	.003
Type of modality	2.92	1,185	.089	.016
Type of visualization	1.10	1,185	.295	.006
Type of modality X type of visualization	0.51	1,185	.474	.003
Verbal cognitive style X type of modality	1.14	1,185	.287	.006
Verbal cognitive style X type of visualization	0.22	1,185	.643	.001
Verbal cognitive style X type of modality X and type of visualization	1.31	1,185	.255	.007

5.4. Discussion

Following up on the first research question regarding the modality effect and its replication, we were able to confirm that modality plays an important role when learning. On the whole participants showed better learning outcomes when learning with spoken text than when learning with written text. This result is in line with the modality principle (Mayer, 2008). It does not necessarily mean, however, that written text should be generally avoided when creating learning materials. The triple interaction effect received in our study suggests that the visual cognitive style and its intensity plays an important moderating role when learning with animations or static pictures with written text.

In the study of Höffler et al. (2010), highly developed visualizers and less developed visualizers were learning from static pictures or animations with written text only. The results of their study showed that highly developed visualizers outperformed less developed visualizers on learning outcome when learning with static pictures, but not when learning with animations (Höffler et al. 2010). Our study aimed to complement the study of Höffler et al. (2010) by investigating whether such results are dependent on the modality of the given explanatory text. We expected that the highly developed visual cognitive style will somewhat compensate disadvantages of the poorer (or more difficult) learning design (static pictures) but only when learning with written text. The use of spoken text, in line with the modality principle (Mayer, 2008) and dual-coding theory (Paivio, 1986), should be less demanding for all participants regardless of the intensity of their visual or verbal cognitive style.

Indeed, visual cognitive style turned out to be an important covariate in our model, but, as expected, only in the written text condition. Namely, the more pronounced the visual cognitive style, the better the learning outcome when learning from static pictures with written text. Hence we replicated the results of Höffler et al. (2010) and additionally found that such an effect occurs only in the written text condition. The effect we found might be called a *partial* ability-as-compensator effect, as a more pronounced visual cognitive style accompanies better results in the static pictures with written text condition but leads to worse results in the animation with written text condition. The spoken text conditions were independent from the magnitude of the visual cognitive style delivering comparable results for all participants regardless of type of multimedia environment (static pictures or animations).

In order to understand these results, the dual-coding theory (Paivio, 1986) should be considered. According to this theory, information is processed in two distinct channels: visual and verbal. When a learning environment simultaneously provides two different types of information which both demand – at least some – visual processing (in our study: static pictures and explanatory written text), this can lead to difficulties, especially for people who prefer the verbal channel when processing information (cf. Jonassen & Grabowski, 1993; Mayer & Massa, 2003). Their visual mental channel is too overloaded to allow them to benefit from the learning environment (Mayer, 2008). Highly developed visualizers, as kind of experts in using and processing visual information, might be able to handle these difficulties better than less developed visualizers. They use their preferred visual channel to retrieve, both from pictures and from written text, the information they need and organize it in their preferred way.

But why is a more developed visual style beneficial when learning from static pictures and written text, yet seems to be a problem when learning from animations and written text? This result can be considered in terms of the expertise reversal effect (Kalyuga, 2007). In the written text condition an animation seems to be an obstacle rather than help for people with a more pronounced visual style. Is that the case because the animation, especially a highly transitory animation, provides a “ready-made” product, which inhibits highly developed visualizers to act in their preferred way, to organize visual information in the way most suitable for them? Do less developed visualizers, when confronted with the animation with written text, rely simply on one of these two visual sources: either on the written text only or on the animation only? Are they more successful when learning from such a learning environment, because they do not try to process this information in depth? These new hypotheses arising from our results still need confirmation, however, they show some similarities to research regarding text comprehension (cf. Kintsch, 1994), suggesting that people with higher prior knowledge learned better from less explicit and coherent texts which might stimulate constructive activities. They are also in line with results from the study of Schnotz and Rasch (2005) suggesting that for learners with higher prior knowledge animations can provide too much help. It hindered such learners from processing information on their own. Is this also the case with highly developed visualizers?

As the analyses on the verbal cognitive style dimension did not provide us with significant results regarding an interaction of verbal cognitive style and learning environment, we also could not confirm our assumption concerning a compensatory effect for people with a high verbal cognitive style. We can assume though that animations are easier to comprehend for learners with less developed visual cognitive style than for learners with highly developed visual cognitive style when the text modality is written.

Summarizing, we can conclude that the modality effect exists and can be considered as a kind of compensator when learning with static pictures and animations, as leading to comparable results on the learning outcome regardless of the cognitive style. Highly developed visual style can be considered as a compensator when learning with static pictures and written text (cf. Huk, 2006; Kalyuga, 2008). Compared to our results the results of Höffler et al. (2010) , take on a new meaning. Our study confirms that the effect of Höffler et al. (2010) is moderated by the presentation modality of the verbal explanation. Highly developed visual cognitive style can also be an “obstacle”, when learning with written text in the animation condition, which can be considered a “too easy hindrance” effect, comparable with an expertise reversal effect (Kalyuga, 2007). Interestingly, this effect does not occur when learning with animation and spoken narration. Additionally, verbal cognitive style – again (cf. Höffler et al., 2010) – does not seem to play a role when learning with static pictures and animations with spoken or written text.

5.5. Limitations and future research

In our study we did not receive significant results regarding the verbal cognitive style, which raises new questions. The most important being if the verbal cognitive style plays a role while learning from text-picture combinations. If yes – what kind of role and under which circumstances? Or maybe the problem lies in the questionnaires? Are they less adequate in assessing verbal cognitive style than visual cognitive style? The problem can also be embedded in the sample. A clear (or highly developed) verbal style is rather rare (cf. Cao & Nishihara, 2012), hence it is difficult to find a sufficient sample of highly developed verbalizers. All in all, future studies should be performed with previously selected groups of highly developed verbalizers and less developed verbalizers in order to shed more light on their learning behavior.

Interesting are also questions regarding a hindering effect of animations with written text in the group of highly developed visualizers, and absence of such an effect in animation/ spoken text condition. Is it an example of an expertise reversal effect (Kalyuga, 2007)? Further studies might give an answer to this question.

Acknowledgements

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CHAPTER 6

EFFECTS OF PACING AND COGNITIVE STYLE ON LEARNING WITH DYNAMIC AND NON-DYNAMIC VISUALIZATIONS WITH NARRATIVE EXPLANATIONS

Abstract: The aim of this study was to investigate the role of visual/ verbal cognitive style and learner/ system control in dynamic and non-dynamic multimedia learning environments. A group of 235 students learned from a computer-based animation or a series of static pictures with spoken explanatory text with or without the possibility to pause, to play, or to fast-forward/ rewind the learning environment (self-paced vs. system-paced). It turned out that animations provided better results on learning outcome than static pictures regardless of cognitive style and type of pacing. Participants also obtained better results when learning with the system-paced environment than with the self-paced one. A significant triple interaction of cognitive style, type of pacing, and type of visualization showed that highly developed visualizers learned poorer with self-paced static pictures than with system-paced static pictures. Additionally, less developed visualizers outperformed highly developed visualizers when learning with self-paced static pictures. No significant effects were found regarding verbal cognitive style.

Keywords: interactive learning environments; interdisciplinary projects; media in education; multimedia/hypermedia systems

Koć-Januchta, M., Höffler, T. N., Prechtl, H., Leutner, D. (submitted). Effects of pacing and cognitive style on learning with dynamic and non-dynamic visualizations with narrative explanations.

Contemporary research on learning with multimedia environments provides more and more findings regarding an impact of multimedia materials' design on learning outcome such as type of visualization (dynamic or non-dynamic; e.g., Höffler & Leutner, 2007; Tversky et al., 2002) or type and range of learner control (system-pacing or self-pacing; e.g., Hegarty, 2004; Schwan & Riempp, 2004; Tabbers & de Koeijer, 2010). However, the picture arising from these findings is still inconsistent and far from complete. Discrepancies between results of studies concern not only advantages of animation over static pictures and vice versa or self-paced design over system-paced design but also the role of individual differences in learning with multimedia environments. In case of some of those considered traits, such as spatial ability (e.g., Huk, 2006; Höffler & Leutner, 2011) or prior-knowledge (e.g., Kalyuga, 2008), the impact on learning outcome seems to be established to some extent. Studies concerning other traits, among them visual-verbal cognitive style, are still inconsistent (cf. Kirschner & van Merriënboer, 2013; Massa & Mayer, 2006). As multimedia learning is becoming more and more popular in education, further research on it is more important than ever.

6.1. Theoretical background

6.1.1. Learning with text and pictures

According to Mayer (2014) learning from a combination of pictures and textsis more effective and leads to better comprehension than learning from words only. Many empirical studies confirm this statement of a multimedia effect (e.g., Carney & Levin, 2002; Clark & Paivio, 1991; Mayer, 2008; 2014; Wittrock, 1978, 1989). In the series of studies reviewed by Mayer (2003a), this effect was proven for different learning environments (dynamic and non-dynamic) students were confronted with. The results are in line with the cognitive theory of multimedia learning depicted in Figure 6.1 (Mayer, 2003a; Mayer & Moreno, 2003), which is based on three basic assumptions:

- The dual channel assumption stating that people process information in two different mental channels (systems): visual for pictorial information and verbal for textual information (cf. dual-coding theory; Paivio, 1978, 1986; Baddeley, 1992).
- The limited capacity assumption stating that cognitive capacity of these two channels (systems) is restricted (Baddeley, 1986, 1992, 1999, 2003; Chandler & Sweller, 1991; Paas & Sweller, 2014)
- The active learning assumption stating that, for meaningful learning to occur learners should actively process information presented to them: select relevant information, organize them into pictorial and verbal representations and integrate them with each other and with prior knowledge (Mayer, 2003a, 2008, 2014).

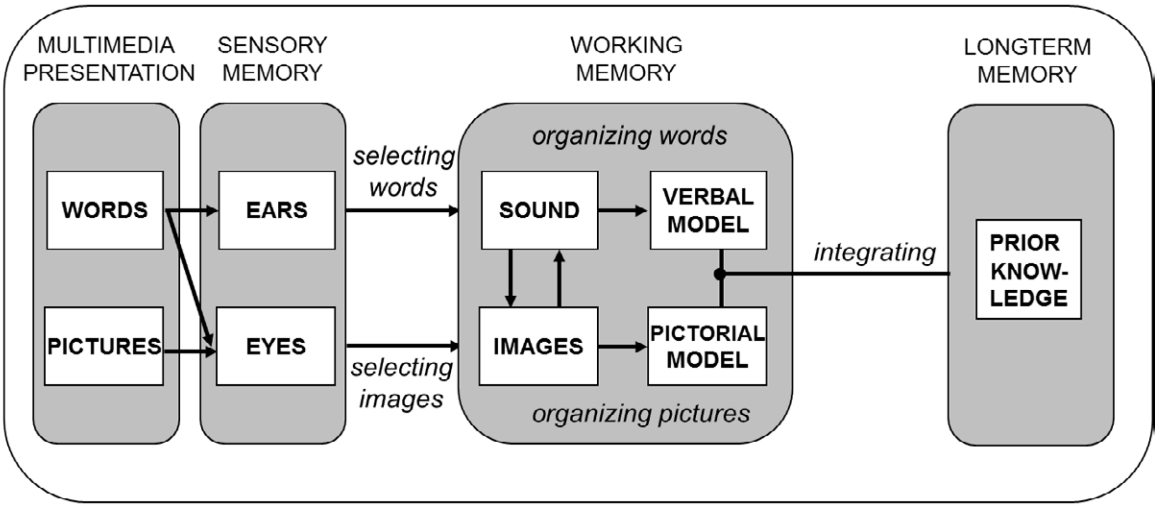

Figure 6.1. Cognitive theory of multimedia learning (Mayer & Moreno, 2003).

The effectiveness of learning with pictures and text is dependent on characteristics of both learners and the multimedia environment (cf. Mayer, 2014; Schnotz & Bannert, 2003). Concerning characteristics of the multimedia learning environments, dynamic (animation) and non-dynamic (static pictures) representations can be differentiated.

6.1.2. Animation versus static pictures

The results of a meta-analysis by Höffler and Leutner (2007) support the assumption that animations on the whole are more beneficial to learners than static pictures (the effect size on learning outcome was d=0.37). These results are in line with the supplantation theory (Salomon, 1979), which states that animations substitute (supplant) internal visualization of a process by providing learners with an external, prefabricated representation of it. Such a help makes learners understand motions of elements contributing to the process. Additionally, it minimizes cognitive load, unlocks working memory resources and, eventually, supports constructing a mental model (Rieber, 1991; Salomon, 1979).

On the other hand, many studies seem not to confirm the animation superiority over static pictures (e.g., Lewalter, 2003; Mayer et al., 2005). A narrative review performed by Tversky et al. (2002) did not show any systematic advantage of animations. Moreover, animations can be more demanding for learners than static pictures due to their transient nature, which, according to cognitive load theory (Sweller, 1994; van Merriënboer & Sweller, 2005), may increase extraneous cognitive load. Learners confronted with animations usually have to retrieve, process and integrate information at a default speed required by the system, which may exceed their working memory capacities (cf. Just & Carpenter, 1986; Hegarty, 2004; Kalyuga, 2008). Additionally, learning with animations may promote a passive way of learning with lower cognitive engagement, and lead to underperformance (Lowe, 2004; Schnotz and Rasch, 2008). Hence, one of the still actual questions is not “if”, but “under which circumstances” animations are better for learning than static pictures, and vice-versa.

6.1.3. Design and interactivity issues

Cognitive overload in multimedia learning can be prevented by following several rules, called multimedia learning principles, concerning the way of constructing multimedia environments (Mayer, 2008). Among them, the modality principle plays an important role stating that presenting computer-based pictorial material with spoken explanatory text (instead of written text) makes the learning material easier to comprehend, as simultaneously following pictures (particularly animated pictures) and reading an on-screen text can be too demanding for the learners' visual channel (in which text is processed at least initially) and lead to cognitive overload (Mayer, 2008). When learning simultaneously from pictures and narration, on the other hand, learners can use the visual channel for processing pictures and the auditory (verbal) channel for processing text, which leads to better learning outcomes by using working memory resources more efficiently and preventing cognitive overload (Baddeley, 1992; Mayer, 2008; Mayer et al., 2003; Mayer & Moreno, 2003; Moreno & Mayer, 1999, 2002).

However, Tabbers (2002) argues that the modality effect is not necessarily based on freeing working memory resources, or on the reduction of cognitive load in the visual channel, but rather on the lack of the necessity for splitting attention between text and pictures, as learners listen to the narration and view the pictures at the same time.

Another important issue that should be addressed when considering multimedia learning is the level and type of interactivity and the implications of *learner control* (Scheiter & Gerjets, 2007). Under this term we understand the response of the learning environment on actions of the learner and vice-versa (Domagk, Schwartz, & Plass, 2010). One of the ways of implementing interactivity is by introducing self-pacing, which gives learners the opportunity to adjust the presentation speed to their needs and, for example, stop, rewind or fast-forward more complicated parts of the learning environment in order to study it more closely (Schnotz & Lowe, 2008). The opposite of self-pacing is system-pacing in which the system controls the speed at which information is presented (cf. Lawless & Brown, 1997).

Studies have shown that system-paced learning environments are cognitively demanding, as preventing re-inspection of learning material can inhibit comprehension (e.g., Hegarty, 1992, 2004; Mason et al., 2013b) and make learners overlook important information (Ainsworth & van Labeke, 2004). Additionally, a large body of evidence shows a beneficial impact of self-pacing when learning with computer-based environments (e.g., Höffler & Schwartz, 2011; Mayer & Chandler, 2001; Schwan & Riempp, 2004; Tabbers & de Koeijer, 2010). For example, there is some evidence that self-pacing promotes the generation of mental models (Schnotz & Lowe, 2008), but it is still not clear if self-pacing is beneficial for comprehension (Mayer & Chandler, 2001) or rather for retention tasks (Stiller, Freitag, Zinnbauer, & Freitag, 2009). However, results of research on the benefits of learner-controlled multimedia learning environments have been inconsistent (e.g., Lunts, 2002). Some researchers argued that in the case of self-paced design the range of implemented interactivity must be carefully considered as a too complicated interface or a too large number of interactive options can lead to cognitive overload (cf. Chandler, 2004; Sweller et al., 1998; Scheiter & Gerjets, 2007). In other words, interactivity (or learner control) may sometimes introduce cognitive overload and, as a result, inhibit learning (Moreno & Mayer, 2007).

Cognitive overload leads us to the cognitive load theory (Sweller, 1994; Paas & Sweller, 2014; Moreno & Park, 2010), which states that there are three sources of cognitive load when learning: intrinsic load (arisen as a consequence of basic cognitive processing involved in schema acquisition), extraneous load (arisen from cognitive processing that is not relevant to the learning topic), and germane load (a result of deep comprehension and integration processes). According to Paas et al. (2003), to enable the learning process, all these three sources of cognitive load together should not exceed the resources of one's working memory. In order to achieve a better learning outcome, *germane* load should be supported, whereas *extraneous* load should be reduced (Moreno & Park, 2010).

The issues of interactivity when learning with multimedia environments are not always considered exclusively regarding cognitive load though. An interesting contribution to this discussion made by Tabbers et al. (2001) compared system-paced and self-paced multimedia instructions with either written or spoken explanatory text. The results showed that the spoken modality yielded better learning outcomes than the written modality in the system-paced condition, while in the self-paced condition the opposite was true – written text condition was more beneficial for learners than the spoken text condition (Tabbers et al., 2001). Comparable effects were obtained in the study of Tabbers (2002): Students attending a multimedia lesson with spoken narration did better on a transfer test than students learning with written text in the system-paced group, while the written text led to better results than the spoken narration in the self-paced group. Additionally, Tabbers (2002) found a modality effect on the mental effort scale, as learning with spoken narration resulted in lower cognitive load than learning with written text.

Last but not least though, when studying the efficacy of interactivity one should consider not only cognitive load and usability issues but also individual characteristics of learners such as, for example, cognitive style (cf. Scheiter & Gerjets, 2007).

6.1.4. Visual-verbal cognitive style in multimedia learning

The visual-verbal cognitive style related research is based on the dual-coding theory (Paivio, 1978, 1986) assumption that when processing information individuals use two cognitive processing channels: visual and verbal. Although both channels are involved in cognitive processes, there is some evidence that some persons are better in using the visual channel and tend to think in pictures (visualizers), while others are better in using the verbal channel and tend to think in words (verbalizers; Mayer & Massa, 2003).

Some studies seem to confirm the relation between visual-verbal dimension and learning outcome in multimedia environment. For example Plass et al. (1998) showed that visualizers profited more than verbalizers from pictorial explanations to a text, while verbalizers profited more from textual explanations. Similar effects were reported by Riding and Douglas (1993). On the other hand, a study of Massa and Mayer (2006) did not find such relation: In their study, visualizers and verbalizers did not differ on learning outcome.

Interesting results were reported in a study of Höffler et al. (2010) with highly and less developed visualizers. In this study highly developed visualizers performed better when learning from static pictures than when learning from animation, while less developed visualizers performed comparably well in both conditions. This result suggests that a more pronounced visual style may help learners to perform a mental simulation of a process on their own when learning from static pictures. In some cases, an external support in form of animation may even inhibit the cognitive processing and hinder the learning process (cf. Schnotz & Rasch, 2005).

In a study of Höffler and Schwartz (2011) the issues of type of visualization (animation versus static pictures), system- versus self-pacing, and visual-verbal cognitive style were addressed. The results showed that self-pacing was more beneficial to learners than system-pacing when learning with animation, but when learning with static pictures the system-paced condition resulted in better learning outcome than the self-paced condition. The cognitive load scores were respectively larger in animation/ system-paced and self-paced/ static picture conditions. Interestingly, and somewhat contradictory to Höffler et al.'s (2010) findings, visualizers performed better than verbalizers when learning with animations. The authors did not obtain a triple interaction (type of pacing x type of visualization x visual-verbal cognitive style), which was obtained by Höffler & Schwartz (2011). However, when comparing these two studies, we have to keep in mind that the first was designed in a written text modality, while the latter used a spoken narration for either a short animation (73 sec) or a sequence of four static pictures.

6.1.5. Objectives of the study

In order to elaborate the findings of Höffler and Schwartz (2011) and Tabbers et al. (2001) regarding type of pacing, modality and visual-verbal cognitive style, we developed a long multimedia lesson – similar to a real learning situation and addressing a complex topic – aiming to answer the following research questions:

- According to Tabbers et al. (2001) a spoken narration is beneficial when learning in a system-paced design, while written text modality is more advantageous in a self-paced design. Our study was designed with spoken narrations: Thus, we can expect overall worse results in the self-paced condition than in the system-paced condition – even if other studies show a general beneficial effect of self-pacing (e.g., Mayer & Chandler, 2001; Schwan & Riempp, 2004; Tabbers & de Koeijer, 2010).
- According to findings of Höffler and Schwartz (2011), the beneficial impact of self-pacing is moderated by type of visualization (animation, static pictures). Can we replicate this interaction when using a longer, more complex learning environment more similar to classroom reality?
- According to the study of Höffler and Leutner (2007), animations are overall more beneficial for learners than static pictures. On the other hand, this beneficial impact on learning seems to be moderated, among others, by visual-verbal cognitive style (Höffler et al., 2010; Höffler & Schwartz, 2011). On the whole will we find animation more advantageous than static pictures, or will the advantages of animation be rather moderated by visual-verbal cognitive style?

- Can we find a triple interaction of cognitive style (visual, verbal), type of pacing (self-pacing, system-pacing), and type of visualization (animation, static pictures), which was not found in the study of Höffler and Schwartz (2011)?

6.2. Method

6.2.1. Participants

Biology students (*N* = 235; 74.5% female), between the age of 18 to 35 years (*M* = 21.69; *SD* = 2.72), from Kiel University and the University of Potsdam in Germany were tested with a computer-based learning environment.

6.2.2. Learning environments, instruments and measures

Four versions of the learning environment on the topic of the primary reactions in photosynthesis were developed in order to answer the research questions: two animated versions (system-paced or self-paced) and two versions with static pictures (system-paced or self-paced). Each version started with an identical short introduction accompanied by a written explanatory text (ca. 1 min. 20 sec.). The introduction was followed by either an animation or a sequence of static pictures accompanied by a vocal explanatory narration (ca. 8 min. 40 sec.).The self-paced versions provided participants with the possibility to play, pause, or to fast-forward/ rewind the learning environment and start it again anywhere and at any time, while the system-paced versions did not offer this possibility, as the learning environment in the system-paced versions went on in its own speed after clicking the play button. Each of the versions of the learning environment lasted for 10 minutes (including introduction) and conveyed the same information. The only difference was that in static pictures versions motions were replaced with arrows (see Figures 6.2 and 6.3). Both system-paced and self-paced versions of the learning environment were switched off after 20 minutes. During this time participants could either view the entire learning environment twice (system-paced condition) or pause, rewind or fast-forward the learning environment as many times as they wanted (self-paced condition).The necessity of giving participants 20 minutes of learning time became apparent during pilot tests with a group of 30 biology students (one simple 10-minute exposition of the learning environment did not lead to satisfactory learning effects). The explanatory narration was read aloud using a female voice.

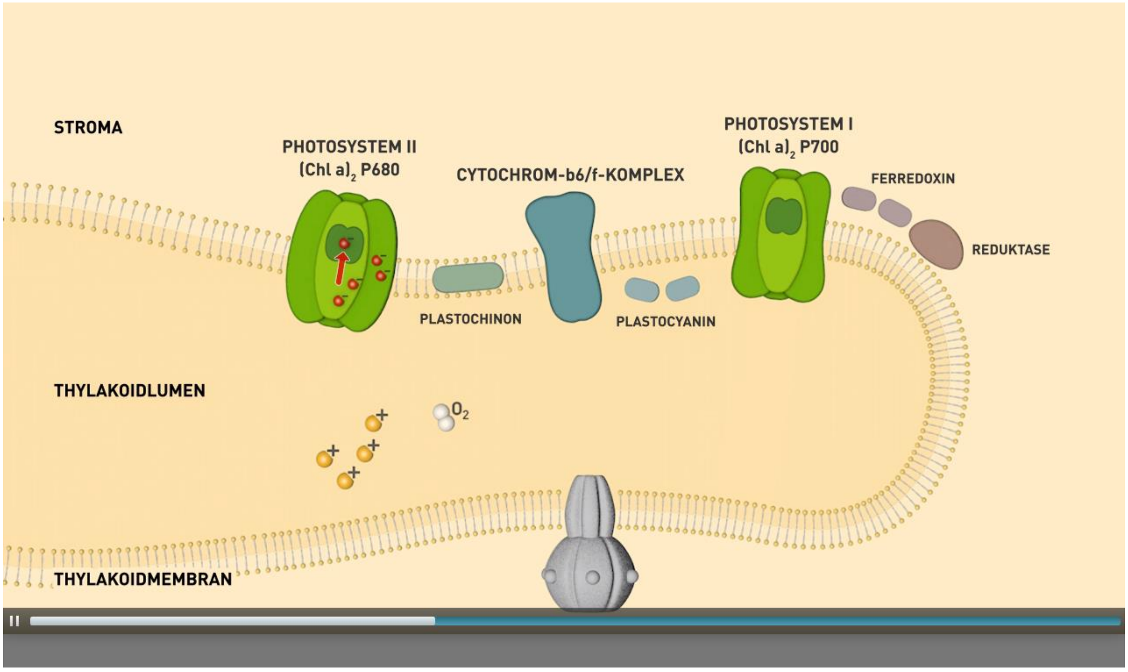

Figure 6.2. Exemplary snapshot of a self-paced static pictures version of the learning environment with an arrow indicating motion of an electron (the red element) within the green depicted Photosystem II.

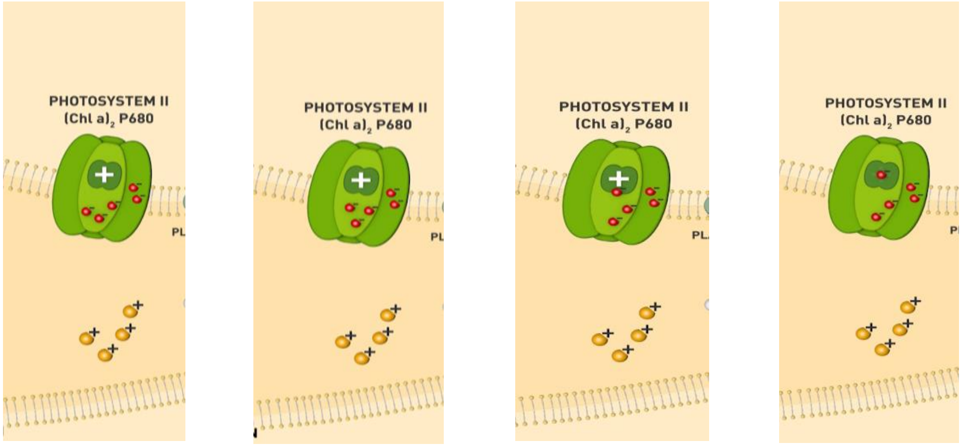

Figure 6.3. Exemplary sequence of snapshots of an animated version of the learning environment showing motion of an electron (the red element) within the green depicted Photosystem II.

In order to measure the visual-verbal cognitive style, the following two questionnaires were used:

- Individual Differences Questionnaire, IDQ (Paivio & Harshman, 1983; 2 scales: visual scale α = .80; verbal scale α = .79),
- Verbalizer-Visualizer Questionnaire, VVQ (Richardson, 1977; 2 scales: visual scale α = .65; verbal scale α = .72).

Participants assessed the level of cognitive load they experienced with two questions (see Table 6.1), with 18 as the possible maximum on the scale.

The topic-related prior knowledge was measured with three questions (one open question and 2 closed questions). The possible maximum of points on prior knowledge was 10.

In order to measure the learning outcome 33 open and closed questions were developed. Cronbach`s alpha for the learning-outcome scale was α = .80. The possible maximum of points on learning outcome was 56.

All open questions assessing prior knowledge and learning outcome were rated by two independent raters. In cases of disagreement, a shared decision was reached by discussion and the help of a third rater. Table 6.1 contains examples of questions used in the study.

Table 6.1: Exemplary items for assessing cognitive load, prior knowledge and learning outcome.

	Exemplary item	Possible answers
Cognitive load	How hard or easy was it to understand the learning material?	a) Very, very easy b) Very easy c) Easy d) Rather easy e) Neither easy nor hard f) Rather hard g) Hard h) Very hard i) Very, very hard
Prior knowledge	Describe as closely as possible what happens during the primary reactions of photosynthesis! Please answer with full sentences!	Open question. Max. 8 points.
Prior knowledge	The reactants of the primary reactions of photosynthesis are:	a) Water, oxygen, ADP b) Carbon dioxide, $NADP^+$, ADP c) Water, $NADP^+$, ADP d) Water, $NADPH+H^+$, ATP
Learning outcome	Which process is immediately driven by the light energy directly?	a) Carbon fixation in the stroma b) Reduction of $NADP^+$ c) Passing of one electron from a chlorophyll molecule to an acceptor d) ATP synthase
Learning outcome	In order to destroy the weed in his garden, a gardener used the DCMU herbicide. This compound prevents electron transfer to plastoquinone. Consequences are the following:	a) $NADPH+H^+$ is still being constructed, the proton gradient is being raised, and the ATP synthesis comes to a standstill. b) The water splitting in the Photosystem II stops, $NADPH+H^+$ and ATP are still being generated. c) $NADPH+H^+$ is not being generated anymore, no more protons are being pumped to the cytochrome b_6f complex, ATP is not being generated anymore d) The water splitting in the Photosystem II is still on, the proton gradient is being raised, ATP is being generated.
Learning outcome	What is the first donor of electrons in the light-dependent reactions? Where do the electrons land at the end?	Open question. Max. 2 points.

6.2.3. Procedure

Participants watched the learning environment and answered questions on a computer. At first they gave information about their age, sex, semester, university major and GPA in high school ("Abitur"). Next they answered 10 statements of the IDQ questionnaire and 15 statements of the VVQ questionnaire regarding the visual-verbal cognitive style. Later they answered three prior knowledge questions and attended the learning environment for 20 minutes. Participants were randomly assigned to one of the four versions of the learning environment. Finally, they assessed their cognitive load (two questions) and answered 33 posttest questions. Each participant had an own computer with a headset to his/ her disposal. The whole procedure lasted for about one hour.

3. Results

The analysis of the data started with performing a principal component analysis (with oblimin rotation) on the four scores of the cognitive style scales (two visual scales and two verbal scales). It showed that scales loaded on two factors (variance accounted for 78%) as expected. The two factor scores were independent from each other (r = -0.09; p = .194). They were used as measures of the level of development for visual or verbal cognitive style.

The participants' level of prior knowledge on the topic was low (M = 1.07, SD = 1.02, with 10 as the possible maximum).

6.3.1. Learning outcome

In order to answer the research questions we analyzed the data within the framework of the General Linear Model (Horton, 1978) with a sequential decomposition of variance, performing analyses for the dependent measure of learning outcome represented as sum of points received for correct answers (with 56 points as the possible maximum). Analyses were conducted separately for visual cognitive style and verbal cognitive style as covariates. In each analysis, the variance of the dependent variable was decomposed by taking the predictors in the following sequence into the linear model: (1) the covariate, (2) the treatment factors and their interaction, (3) the two interactions of cognitive style and each of the treatment factors, and (4) the triple interaction of cognitive style and the two treatment factors. We expected following effects to be statistically significant:

- a main effect of type of pacing (system-pacing outperforms self-pacing),
- a main effect of type of visualization (animation outperforms static pictures),
- an interaction of type of visualization and type of pacing indicating that the beneficial impact of self-pacing is moderated by type of visualization,
- an interaction of cognitive style and type of visualization indicating that the impact of visualization is moderated by cognitive style,
- a triple interaction of cognitive style, type of pacing, and type of visualization indicating that the interaction effect of the treatments is moderated by cognitive style.

6.3.1.1. Visual cognitive style

In the analysis with visual cognitive style as the covariate, we received the following effects:

- A main effect of type of pacing, $F(1,227) = 2.76$, p (one-tailed, 1-*df*-test) = .098/2 = .049, η^2=.012; $M_{\text{self-paced}} = 29.32$; $SD_{\text{self-paced}} = 9.17$; $M_{\text{system-paced}} = 31.19$; $SD_{\text{system-paced}} = 9.09$.
- A main effect of type of visualization, $F(1,227) = 16.81$, $p < .001$, η^2=.069; $M_{\text{animation}}$= 32.56; $SD_{\text{animation}}$= 8.33; $M_{\text{static picture}}$= 27.94; $SD_{\text{static picture}}$= 9.41.
- No significant interaction of type of pacing and type of visualization, $F(1,227) = 0.18$, $p = 0.668$.

- No significant interaction of visual cognitive style and type of visualization, $F(1,227) = 0.57$, $p = 0.451$.
- A triple interaction of visual cognitive style, type of pacing, and type of visualization, $F(1,227) = 5.08$, $p = .025$, $\eta^2=.022$, see Figure 3.

Table 6.2 shows the results of all effects of this analysis, and Figure 6.4 displays the significant triple interaction.

Table 6.2: Results of the analysis with visual cognitive style (learning outcome).

Effect	*F*	*Df*	*p*	η^2
Visual cognitive style	0.99	1,227	.320	.004
Type of pacing	2.76	1,227	.098	.012
Type of visualization	16.81	1,227	< .001	.069
Type of pacing X type of visualization	0.18	1,227	.668	.001
Visual cognitive style X type of pacing	2.81	1,227	.095	.012
Visual cognitive style X type of visualization	0.57	1,227	.451	.003
Visual cognitive style X type of pacing X type of visualization	5.08	1,227	.025	.022

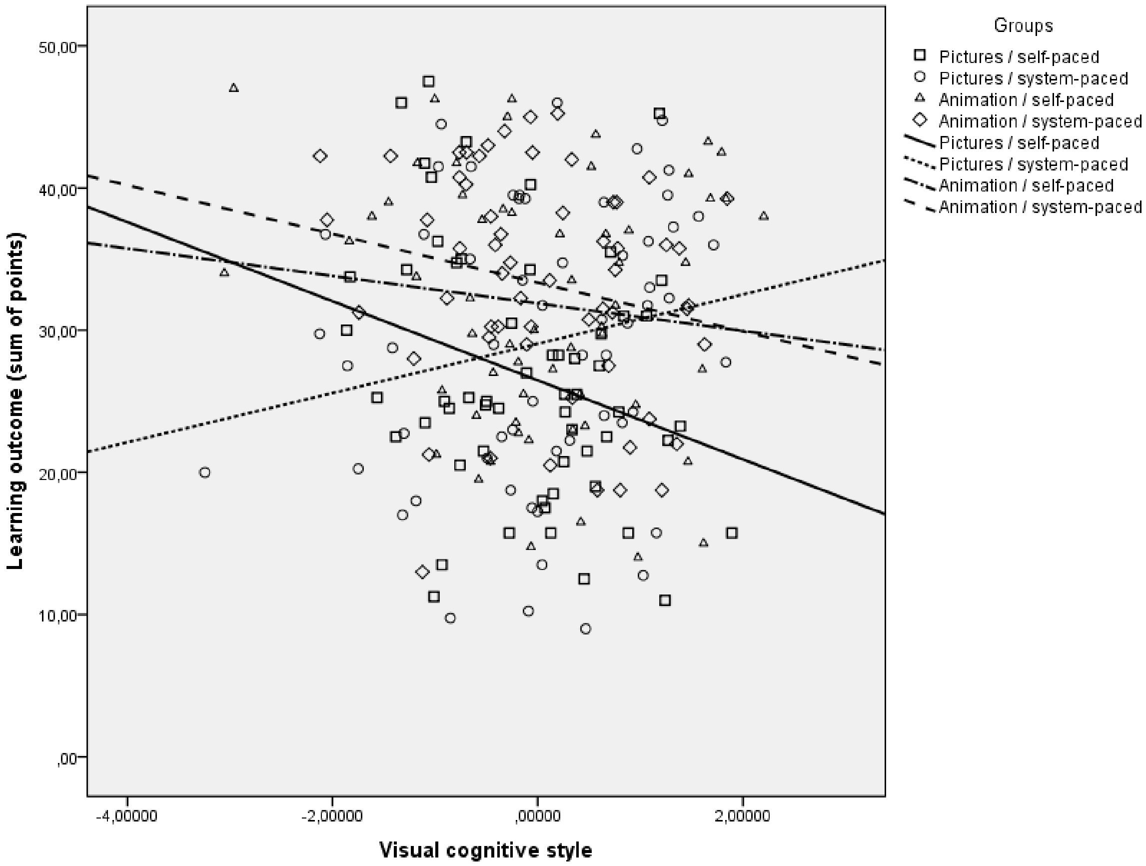

Figure 6.4. Learning outcome as a function of visual cognitive style, type of pacing, and type of visualization.

Figure 6.4 shows that a higher visual cognitive style is associated with better learning outcomes when learning with *system-paced static pictures.* Furthermore, higher visual cognitive style accompanies poorer learning outcomes with *self-paced static pictures.* For lower visual cognitive style, the opposite is true. Intriguingly, visual cognitive style seems to make no difference when learning with animations. In other words, visual cognitive style correlates negatively with learning outcome when learning with *self-paced* learning environment based on *static pictures* (r = -.28). This correlation decreases when learning both with self-paced and system-paced *animation* (r = -.12 and r = -.20, respectively) and changes to a weak positive correlation when learning with a *system-paced* learning environment based on *static pictures* (r = .19).

Hence, the results of this analysis indicate both the expected effect of type of visualization in favor of animation (learning with animation outperforms learning with static pictures) as well as the expected effect of type of pacing in favor of system-pacing (system-pacing gives better learning outcome than self-pacing). Furthermore, this analysis indicates that, in the static pictures condition, learning outcome depends on visual cognitive style with a weak negative correlation for the self-pacing condition and a weak positive correlation for the system-pacing condition.

For illustrative purposes, the triple interaction is again displayed in Figures 6.5a and 6.5b based on a median split of visual cognitive style into less developed visualizers (LDV, N = 117, 73.5% female, age: M = 21.65; SD = 2.80 years) and highly developed visualizers (HDV, N = 118, 75.4% female, age: M = 21.73; SD = 2.66 years).

Static pictures condition (Figure 6.5a). Highly developed visualizers (HDV) had a higher number of points on the learning outcome test when learning with system-paced static pictures (M = 29.80, SD = 9.59) than when learning with self-paced static pictures (M = 23.95, SD = 7.41), simple effect $F(1,227) = 6.79$, $p = .010$, $\eta^2 = .029$.

When learning with self-paced static pictures, less developed visualizers (LDV; M = 29.59, SD = 9.47) outperformed highly developed visualizers (HDV, M = 23.95, SD = 7.41) on learning outcome, simple effect $F(1,227) = 6.00$, $p = .015$, $\eta^2 = .026$.

The differences between LDV and HDV on learning outcome when learning with system-paced pictures, and between self-paced pictures and system-paced pictures in the group of less developed visualizers (LDV), were not significant (all simple main-effects $F < 1$).

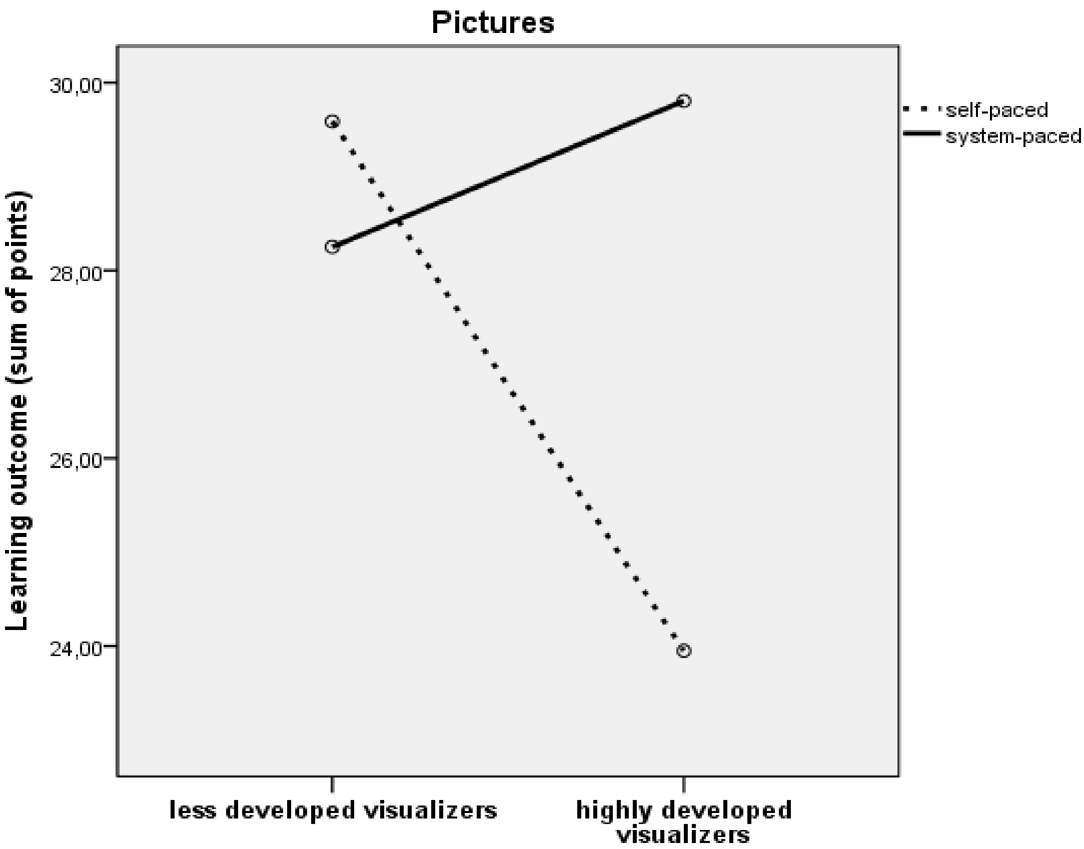

Figure 6.5a. Learning outcome (sum of points) as a function of level of visual cognitive style, type of pacing and type of visualization in the static picture condition.

Animation condition (Figure 6.5b). The difference between LDV and HDV on learning outcome when learning with system-paced animation or with self-paced animation, as well as the difference between self-paced animation and system-paced animation in both groups (LDV and HDV), were not significant (all simple main-effects $p > .10$).

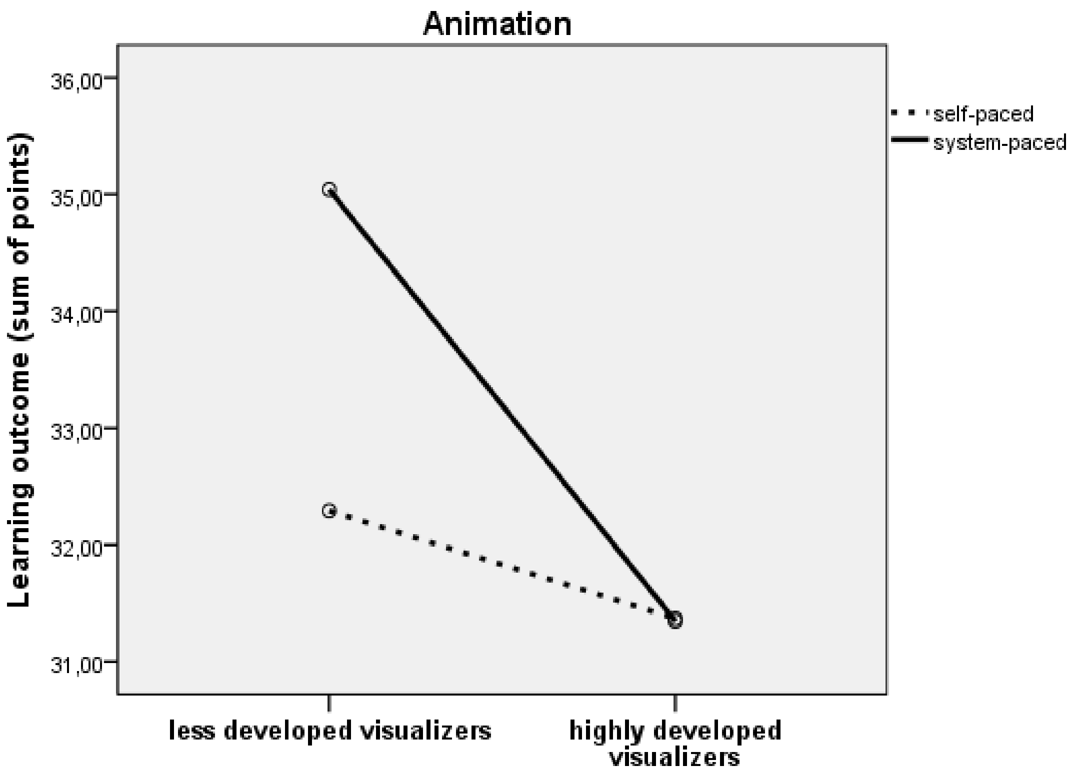

Figure 6.5b. Learning outcome (sum of points) as a function of level of visual cognitive style, type of pacing and type of visualization. Animation condition.

6.3.1.2. Verbal cognitive style

In the analysis with verbal cognitive style as the covariate we received the expected effect of type visualization, $F(1,227) = 16.97$, $p < .001$, η^2=.070: Animation ($M_{animation}$ = 32.56; $SD_{animation}$ = 8.33) outperformed static pictures ($M_{pictures}$ = 27.94; $SD_{pictures}$ = 9.41. We did not, however, obtain any other significant effects (all $p \geq .10$; Table 6.3).

Table 6.3: Results of the analysis with verbal cognitive style (learning outcome).

Effect	*F*	*df*	*p*	η^2
Verbal cognitive style	1.73	1,227	.190	.008
Type of pacing	2.73	1,227	.100	.012
Type of visualization	16.97	1,227	< .001	.070
Type of pacing X type of visualization	0.12	1,227	.731	.001
Verbal cognitive style X type of pacing	0.50	1,227	.482	.002
Verbal cognitive style X type of visualization	1.74	1,227	.189	.008
Verbal cognitive style X type of pacing X type of visualization	1.56	1,227	.214	.007

6.3.2. Cognitive load

As the analysis on learning outcome with visual cognitive style as a covariate yielded several significant effects, we also performed analyses for the dependent measure of cognitive load represented as sum of points received in the cognitive load scale (with 18 points as the possible maximum; the more points, the higher the cognitive load) and visual cognitive style as covariate. Again we analyzed the data within the framework of the General Linear Model (Horton, 1978) with a sequential decomposition of variance.

In the analysis with visual cognitive style as the covariate we received one significant effect: the triple interaction of visual cognitive style, type of pacing, and type of visualization, $F(1,227) = 4.17$, $p = .042$, $\eta^2=.018$.

Table 6.4 shows the results of all effects of this analysis and Figure 6.6 displays the significant triple interaction.

Table 6.4: Results of the analysis with visual cognitive style (cognitive load).

Effect	*F*	*df*	*p*	η^2
Visual cognitive style	0.01	1,227	.918	.000
Type of pacing	0.22	1,227	.640	.001
Type of visualization	2.63	1,227	.106	.011
Type of pacing X type of visualization	0.09	1,227	.765	.000
Visual cognitive style X type of pacing	0.25	1,227	.621	.001
Visual cognitive style X type of visualization	0.12	1,227	.732	.001
Visual cognitive style X type of pacing X type of visualization	4.17	1,227	.042	.018

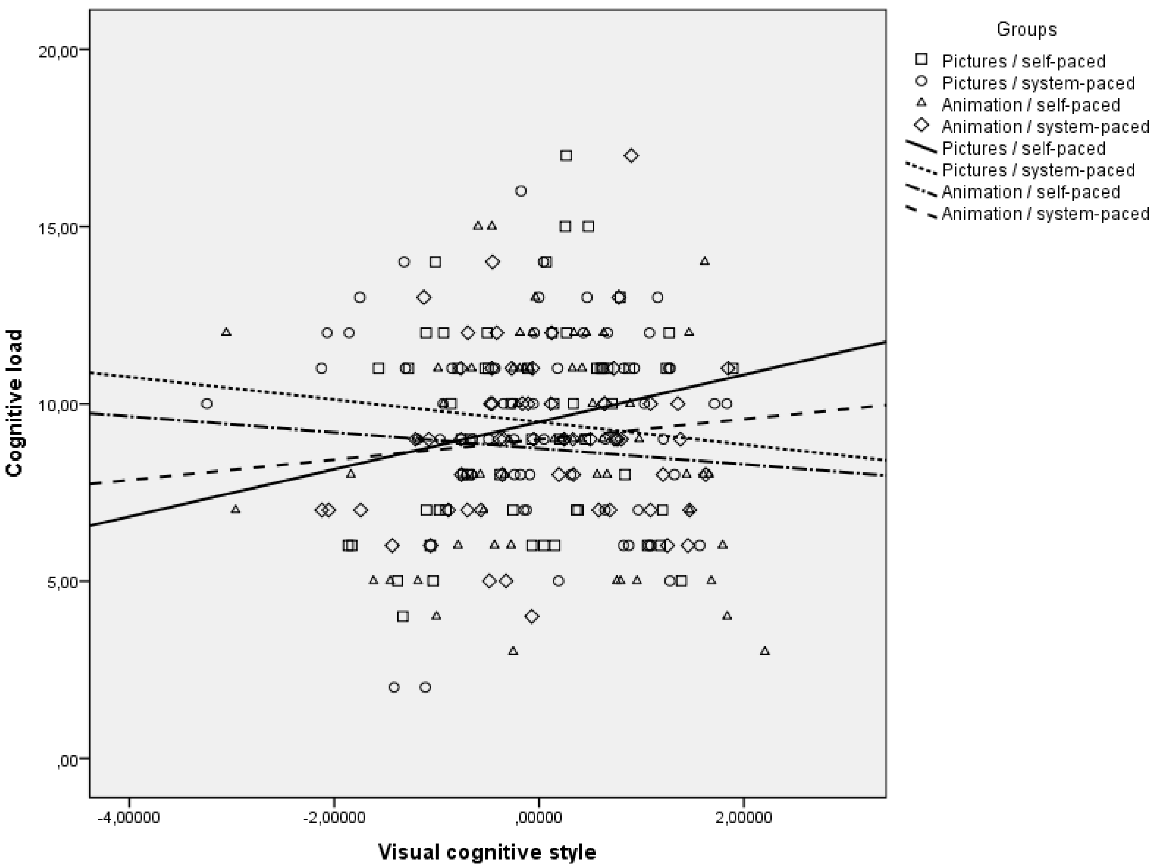

Figure 6.6. Cognitive load as a function of visual cognitive style, type of pacing and type of visualization.

As can be seen in Figure 6.6, a highly developed visual cognitive style comes with a higher level of cognitive load when learning with self-paced static pictures. Respectively, a highly developed visual cognitive style comes with a slightly lower level of cognitive load when learning with system-paced static pictures. However, all correlations of visual cognitive style and cognitive load are weak and have values of $r = .20$ for self-paced static pictures, $r = -.12$ for system-paced static pictures, $r = -.09$ for self-paced animation, and $r = .11$ for system-paced animation. However, the analysis indicates that, in the static pictures condition, cognitive load depends on visual cognitive style with a weak positive correlation for the self-pacing condition and a weak negative correlation for the system-pacing condition. Interestingly, in the animation condition the opposite is true: Cognitive load depends on visual cognitive style with a weak positive correlation for the system-pacing condition and a weak negative correlation for the self-pacing condition. The difference between correlation indicators in the static pictures condition is significant, p (one-tailed, 1-*df*-test) = .089/2 = .044, while the difference between correlation indicators in the animation condition does not reach significance, $p = 0.288$.

6.4. Discussion

The goal of our study was to investigate the role of visual-verbal cognitive style when learning with animation or static pictures and with system- versus self-paced design. We created and applied a long (10 min.) computer-based learning environment similar enough to an authentic multimedia lesson which addressed a complex topic (primary reactions in photosynthesis) and which implemented the modality principle (with spoken narration) in four different versions: system-paced animation, self-paced animation, system-paced static pictures and self-paced static pictures. Firstly, regarding the pacing effect, learners from system-paced groups outperformed learners from self-paced groups on learning outcome. As learning environments applied in our study were accompanied by vocal narration this result is in line with findings of Tabbers et al. (2001) and confirms that when using a vocal narration system-paced environments are more beneficial to learners than self-paced ones. Tabbers (2002) explains this effect by arguing that listening to a spoken narration, in contrast to reading a text, is a passive process and therefore more suitable when viewing linear presentations. A written text should evoke a more active and strategical way of learning and hence better fit with the self-pacing mode (Tabbers, 2002). Is then applying a spoken narration to self-paced learning environments a logical contradiction? After all, listening to a spoken text is somewhat beyond the control of the listener: One cannot (or at least not easily, depending on the type of design) skip irrelevant parts of the text or words. Simply put, one cannot attend to the text in a way one is used to when reading, as for example by quickly scanning or re-inspecting parts of the text, by paying attention only to first letters of a word, and so on. Many eye-tracking studies showed that people differ in their reading strategies by making more or fewer re-inspections or forward fixations on the text (e.g., Hyönä et al., 2002; Rayner, 1998). Therefore, do external restrictions of applying one's text-processing habits cause an additional cognitive load which results in a worse learning outcome? That question might be worth investigating.

Regarding the second research question, we could not replicate the interaction effect of type of pacing (self-pacing versus system-pacing) and type of visualization (animation versus static pictures) from the study of Höffler and Schwartz (2011). In that study participants, when learning with animation, performed better in the self-pacing condition than in the system-pacing condition, while among participants learning with static pictures, system-pacing was more effective than self-pacing. Höffler and Schwartz (2011) argued that the results obtained in the animation condition are in line with other findings regarding studying a complex topic requiring a simultaneous integration of many elements (e.g., Hasler et al., 2007). The reversed result in the static picture condition was considered as unexpected and explained in the context of the peculiarity of such a learning environment (static pictures + narration + self-pacing). However, in our study such an interaction effect was not found, neither in the analysis with visual cognitive style as a covariate nor with verbal cognitive style. It is especially intriguing why we were not able to find a self-pacing superiority in the animation condition. Animation, with its transient character, should be especially destined to lead to better learning results when learners have the possibility to control and adjust its flow (e.g., Domagk et al., 2010), as self-pacing might help learners to manage the intrinsic load by segmenting the learning environment on their own (cf. Mayer & Moreno, 2003). One reason for this unexpected finding might lie in the design of our learning environment. Namely, in the self-paced condition while the animation provided the possibility to play, pause, and fast-forward/ rewind the learning environment, it was still difficult to return exactly to a chosen part of the learning environment as it was not divided into specific segments. Participants could, for example, rewind the animation but they were never absolutely sure that they would find this particular passage they were looking for. Such a self-paced design, offering only restricted control over the learning environment accompanied by a spoken, long narration, might have inhibited learning. On the other hand, many studies showed that even minimal application of learner control, such as, for example, using only a “play” button with which learners can start the learning environment, may be beneficial for learners (Mayer & Chandler, 2001; Hasler et al., 2007). All in all though, we did not obtain the expected improvement of learning outcome when learning with self-paced animation which would have been in line with previous studies (Höffler & Schwartz, 2011; Mayer & Chandler, 2001; Schwan & Riempp, 2004).

As to the third research question, we once again obtained an overall superiority of animation versus static pictures, which is in line with findings of Höffler and Leutner (2007). Interestingly, this result appeared in both analyses: with visual cognitive style as a covariate and with verbal cognitive style as a covariate. Regardless of cognitive style, animation seems to be more beneficial to learners than static pictures, supporting them decreasing cognitive load and freeing parts of resources of working memory by providing learners with an external "ready-made" representation of a process (Rieber, 1991; Salomon, 1979).

Finally though, the results from our study seem to support the assumption that the impact of treatment factors is moderated by visual cognitive style. Instead of a simple interaction of cognitive style and type of visualization, which could have provided us with more evidence regarding usability of animations and static pictures for visualizers and verbalizers, we found a triple interaction of visual cognitive style, type of pacing, and type of visualization indicating that this relation is more complex. Quite unexpectedly though, the obtained interaction effect showed a negative relation between visual cognitive style and learning outcome when learning with self-paced static pictures (r=-.28). Additionally, more detailed median-split analyses of this effect showed that visual cognitive style was involved only when learning from static pictures (no significant effects for animation) and was related to the decrease of the performance in the group of highly developed visualizers (HDV). When learning with self-paced static pictures, visual cognitive style was also positively correlated with experienced cognitive load (r=.20); that is, the higher the score on the visual cognitive style scale, the higher the experienced cognitive load. At the same time, HDV did not show any superiority to LDV in terms of learning outcome in any condition. Although this result is partly in line with findings of Höffler and Schwartz (2011) showing the same pattern of decrease of performance when learning with self-paced static pictures, the additional information that the mentioned decrease occurs in the HDV group is surprising. We would rather have expected an improvement of performance in this group, as some studies indicated that HDV perform better when learning with static pictures than LDV (cf. Höffler et al., 2010; Schnotz & Rasch, 2005). However, the study of Höffler et al. (2010) was conducted with written text, which might suggest that the advantages of animations for HDV are related to the modality of the accompanying explanatory text. Höffler and Schwartz (2011) pointed out that a non-typical design of the learning environment, in this case consisting of a set of control buttons for applying self-pacing in a static pictures condition, might explain worse learning outcomes in this experimental condition. Additionally self-pacing can have a negative effect on learning when learning with spoken narration (Tabbers, 2002). Our study showed that a combination of spoken narration, static-pictures and learner control (self-pacing) may impair effectiveness of learning and increase experienced cognitive load, but only in relation to higher scores on the visual cognitive style scale. Does coping with two different tasks at the same time – encoding and understanding of static pictures in order to perform a mental visualization of the depicted process (intrinsic and germane load) and managing a set of control buttons in a non-typical learning environment (extraneous load; Sweller, 1994; Paas & Sweller, 2014) – generate too much cognitive load? But then, why only in the group of HDV? One might speculate that in the self-paced/ static pictures condition, HDV, as individuals who are used to think in pictures (Mayer & Massa, 2003) and who hence have more experience in managing pictorial information, might have trusted their skills in decoding pictorial information more than LDV did, and therefore also invested more learning effort than LDV. The presence of high cognitive effort indicates a positive correlation of visual cognitive style and experienced cognitive load. Speculating further, as opposed to LDV, HDV might have strived to not only remember given facts but also to integrate them into a mental model by understanding them more deeply. However, such an attitude might have been kind of a trap as the sum of cognitive load cannot exceed the capacities of working memory (Paas et al., 2003). Additionally, the design of our study might have not fostered enough deep learning processes, as the time for inspecting the learning environment was set (20 min) and rather short for such a complex topic. An attempt to comprehend the learning material on a deeper level in a rather short time might have exceeded available cognitive capacities in the HDV group, leading to cognitive overload and, in result, poorer learning outcome. Moreover, our posttest included mostly retention tasks (26 out of 33) and thus promoted simple recalling of facts rather than deeper comprehension. Hence, LDV, who might have contented themselves with more superficial learning, performed better on the learning outcome test, simply by remembering more facts than HDV in the self-paced/ static pictures condition. Interestingly, none of the other experimental conditions applied in our study (system-pacing/ static pictures, self-pacing/ animation, system-pacing/ animation) have inspired HDV to make such a pronounced (though unsuccessful) cognitive effort as the self-pacing/ static pictures condition.

6.4.1. Limitations

The above given possible explanation of the triple interaction of cognitive style, type of pacing, and type of visualization is just a speculation. Unfortunately some limitations of our study hinder more certain interpretation. Namely, we did not observe the intensity of usage of control buttons. Hasler et al. (2007) claims though, that self-pacing is beneficial even if used infrequently. Nevertheless, actual information not only about the frequency but also the manner in which participants took advantage of learner control would have helped to explain our results more adequately. Another limitation is an absence of segmentation of the learning material in the self-paced condition (cf. Mayer & Moreno, 2003), which would have facilitated profiting from learner control usability.

6.4.2. Conclusions and further research

There are considerable controversies regarding different multimedia learning features' advantages (such as the level of interactivity and the type of visualization) as well as the role of cognitive style. Our study contributes not only to an understanding of the consequences of combining different types of visualization and pacing in a rather long and complex learning environment with a spoken narration, but also underlines the importance of learners' individual differences for learning outcome. Namely, our study showed that a spoken narration fits better with system-paced environments and supports learning with animations. Apparently, the positive effects of system-pacing and dynamic visualizations especially occur when applying long, ecologically valid environments. On the other hand, the combination of spoken narration, self-pacing and static pictures worsens learning outcomes and increases cognitive load in the group of highly developed visualizers. Possibly, cognitive effort invested in deep learning, when having relatively little time, exceeded working memory capacities in this group of participants, causing disintegration of the learning process and, eventually, worsened learning outcome. In order to better understand and explain this result, the intensity of the usage of learner control buttons as well as its range should be considered. Further research might also apply eye-tracking methodology to observe eye movements in groups of higher and lower developed visualizers when learning with self-paced (segmented) or system-paced dynamic and non-dynamic representations.

Acknowledgements

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CHAPTER 7

OVERALL DISCUSSION

This doctoral project investigated the role of visual-verbal cognitive style when learning with diversely designed computer-based multimedia learning environments in three studies. It aimed to address such questions as: Are dynamic visualizations (animations) better than non-dynamic ones (static pictures)? Does the modality of explanatory text (spoken versus written) play a role? Is learner control (self-pacing) always more beneficial than system-pacing? Is the visual-verbal cognitive style a moderator which interacts with the type of design and manifests its influence in learning outcome? Can we observe behavioral differences between visualizers and verbalizers with usage of eye-tracking systems? The following review of the results of the three doctoral-project studies follows the three blocks of research questions posed in Chapter 3.

7.1. Cognitive style and type of visualization

7.1.1. Main effect of type of visualization

Previous research (cf. Höffler & Leutner, 2007; Tversky et al., 2002) has not brought a clear-cut answer to the question whether animations or static pictures are more advantageous to learners. The results obtained in this doctoral project give no clear answer either. That is, the second study, comparing system-paced animations and static pictures with written versus spoken explanatory text, did not demonstrate any simple advantage of either dynamic or non-dynamic visualizations in respect of learning outcome. However, results achieved in the third study, comparing system-paced and self-paced visualizations (animations versus static pictures) accompanied by a spoken narration supported the assumption of animation superiority (Höffler & Leutner, 2007). Interestingly, the expected interaction of type of pacing and type of visualization from the study of Höffler and Schwartz (2011) did not occur in the third study, hence the effect of pacing moderated by type of visualization, showing that self-pacing is more beneficial for learning with dynamic visualizations (animation), while system-pacing yields better results with non-dynamic ones (static pictures), could not be replicated. The overall supremacy of animation received in the third study may have been a result of using verbal explanations in spoken modality, which is, according to some views, particularly beneficial when learning with multimedia and, more accurately, with dynamic multimedia (cf. Mayer, 2008; Paivio, 1986). These two results showing either an absence of the main effect of type of visualization (the second study) or a presence of this effect (the third study) in favor of animation indicate more complex relations regarding the utility of computer-based multimedia. What role, for example, does cognitive style play in it?

7.1.2. Interaction of type of visualization and cognitive style

The results regarding the comparison of dynamic and non-dynamic visualizations with regard to the level of either visual or verbal cognitive style indicate an important role of *visual* cognitive style, while no significant interaction effects regarding *verbal* cognitive style were found. The second study confirmed that highly developed visual style is related to better learning outcome when learning with static pictures, which is in line with findings of Höffler et al. (2010) but, at the same time, in contradiction to other findings (cf. Chen & Sun, 2012; Höffler & Schwartz, 2011). Although previous research (Chen & Sun, 2012; Höffler et al., 2010; Höffler & Schwartz, 2011) showed a connection between the intensity of visual cognitive style and success in learning with animations or static pictures, the direction of this connection is still unclear. One way of interpretation of this inconsistency of results may focus on design diversity, pointing out the influence of the type of modality and the level of learner control as a possible explanation (cf. Tabbers et al., 2001, Tabbers, 2002). The issues of modality will be addressed in the next chapter; it is to underline though that visual cognitive style seems to influence the learning outcome differently depending on the modality, often in combination with the type of pacing.

Another interpretation path leads us to the ability-as-compensator hypothesis (Mayer & Sims, 1994), the expertise reversal effect (cf. Kalyuga 2007; 2008), as well as to the dual-coding theory (Paivio, 1978, 1986), the cognitive theory of multimedia learning (Mayer, 2003a, 2008), and the cognitive load theory (Paas & Sweller, 2014; Sweller, 1994, 1999). Namely, results from the second study, achieved in the written text condition, showed that more pronounced visual style accompanies a better learning outcome when learning with static pictures but a worse learning outcome when learning with an animation. Such a pattern of results is similar to the one from the study of Höffler et al. (2010). In line with the ability-as-compensator hypothesis (cf. Höffler & Leutner, 2011; Mayer & Sims, 1994), it indicates that a poorer, or more cognitively demanding design, such as a series of static pictures, requires a certain amount of cognitive skills or abilities in order to profit from it. In case of the second study from this doctoral project, static pictures might have been too complicated to comprehend for individuals with less pronounced visual cognitive style. According to the definition of Mayer and Massa (2003), visualizers think in pictures, or, following the definition of Riding (1994), they process information using pictorial mental representations. Hence, they are more experienced in processing pictorial information than verbalizers or less developed visualizers. According to the dual-coding theory of Paivio (1986) and the cognitive theory of multimedia learning (Mayer, 2003a, 2008), individuals process information in two mental channels – visual and verbal – but some of them prefer the verbal channel (verbalizers) and others the visual channel (visualizers; cf. Jonassen & Grabowski, 1993; Mayer & Massa, 2003). In the second study, learners were confronted with learning materials consisting of static pictures and written text, which require more visual than verbal processing, hence learners with a lower developed visual cognitive style coped worse than learners with a higher developed visual cognitive style. In terms of cognitive load theory (Sweller, 1994, 1999), a series of static pictures with written text does not cause too much cognitive load in learners with higher visual cognitive style, but still enough to promote meaningful learning. At the same time, this type of design causes cognitive overload in learners with lower visual cognitive style.

On the other hand, an animation with written text, as it provides an external pictorial representation, may inhibit the learning process in the group with a more pronounced visual cognitive style, as it was found in the second study. This is in line with the expertise reversal effect (cf. Kalyuga 2007; 2008), as the animation provides a "ready-made" visualization, which precludes creating an own one. The latter would probably better fit to one's previous knowledge and routines in building mental models. However, the question of the role of written text modality in this relation is still open.

The results of the third study complete the findings from the second study by indicating that static pictures can cause a drop in the level of learning outcome in the group of highly developed visualizers when combined with spoken modality and self-paced design. What is the relation between type of modality and cognitive style then?

7.2. Cognitive style and type of modality

7.2.1. Main effect of type of modality

The results of the second study support the modality effect (cf. Mayer, 2008) showing that, generally, learners achieve better learning outcomes when learning with spoken narration rather than with written explanatory text. This finding is in line with previous research (cf. Mayer, 2008; Mayer et al., 2003; Moreno & Mayer, 1999). The absence of a significant interaction of type of modality and type of visualization indicates that spoken narration is beneficial to learners regardless of the type of visualization (animation versus static pictures).

7.2.2. Interaction of type of modality and cognitive style

The triple interaction effect of visual cognitive style, type of modality, and type of visualization from the second study shows that, while the spoken text condition yields comparable results for all learners, the written text condition makes a difference. That is, when learning with written explanatory text and *static pictures*, higher visual cognitive style accompanies better learning outcome. However, when learning with written explanatory text and *animation*, higher visual cognitive style accompanies poorer learning, which is in line with findings of Höffler et al. (2010). Moreover, it adds to the findings of Höffler et al. (2010) the important information that such a pattern of results occurs when the modality of the explanatory text is written. In other words, the partial ability-as-compensator effect from the study of Höffler et al. (2010) is moderated by the modality of the explanatory text.

This interesting result may be considered in the context of the results from the study of Tabbers et al. (2001), which concerns an interaction of type of modality and type of pacing. According to Tabbers (2002), system-paced environments provide better learning outcome when combined with spoken modality, while self-paced environments lead to better results when accompanied by written explanatory text. As all learning environments applied in the second study were system-paced, the presence of the modality effect, showing superiority of the environments with spoken narration over the ones with written text, is not surprising (cf. Mayer, 2008). The above mentioned positive correlation of visual cognitive style and learning outcome obtained in the written text/ static pictures condition may indicate that this particular type of learning design is especially demanding for the visual mental channel (cf. Paivio, 1986; Mayer, 2008). Hence, only learners with higher visual cognitive style can profit from it. The negative correlation of visual cognitive style and learning outcome obtained in the written text/ animation condition recalls again the expertise reversal effect (Kalyuga, 2007) described in the previous chapter, as too much external help, provided by animation, might have impeded generative information processing information in the group of "experts on pictures" (that is, individuals with a more pronounced visual cognitive style). Additionally, the written text modality combined with system-pacing might have hindered creating an own mental model even more (cf. Tabbers, 2002). All in all, the combination of written text modality, system-pacing, animation, and high visual cognitive style seemingly resulted in a deterioration of the learning outcome.

7.2.3. Interaction of type of modality, type of pacing and cognitive style

The results obtained in the third study also showed that, on the whole, when using learning environments accompanied by a spoken explanatory narration, system-pacing is more effective than self-pacing. That is in line with findings of Tabbers et al. (2001) and Tabbers (2002), who explain this effect pointing out that listening to a spoken narration is a passive process, whereas reading a text is an active one. Spoken narration fits better in a system-paced mode and therefore yields better learning outcomes (Tabbers, 2002). One may also argue that a spoken narration is not fully controllable by learners, at least not to such an extent as written text, which can be more easily processed in the way the learner is used to. Namely, when attending a written text, one can more easily skip parts of it or re-read some words or paragraphs at will. When listening to a spoken narration one cannot fully apply personal "reading habits", which may hinder cognitive processes and lead to cognitive overload. Another possible explanation to this result can be derived from eye-tracking studies regarding reading comprehension (e.g., Rayner, 1992, 1998; Rayner, Chace, Slattery, & Ashby, 2006).

How much does the comprehension depend on eye-movements? Can the situation, when movements of one's eyes are imposed rather than arising from one's sovereign decisions (as is to some extent the case when listening to an explanatory narration) inhibit comprehension? For example, there is some evidence of a functional role of eye movements when performing mental visualizations such as recalling a scene from memory (Johansson, Holsanova, Dewhurst, & Holmqvist, 2012). In thestudy of Johansson et al. participants who could make any eye movements they wanted during recollection of the scene outperformed participants whose eye movements were constricted, hence constriction of eye movements impaired the mental visualization process. Can it be that constriction or even external steering of eye movements and, consequently, of attention, impairs comprehension? Such a hypothesis may be worth investigating in future studies.

The third study provided also an interesting contribution to the understanding of relations between visual cognitive style, type of visualization and type of pacing when learning with a multimedia instruction accompanied by a spoken explanatory narration. That is, highly developed visualizers performed significantly worse when learning in the static pictures/ self-pacing condition. Additionally, in this condition, the experienced cognitive load was positively correlated with visual cognitive style. That might have been a consequence of a non-typical design applied in this condition: a set of control buttons combined with static pictures and a vocal narration (cf. Höffler & Schwartz, 2011). Another interpretation leads us again to cognitive load theory (Sweller, 1994; van Merriënboer & Sweller, 2005). That is to say, one can argue that this specific multimedia design provided too much cognitive load: Intrinsic and germane load involved in decoding and processing static pictures added up with controlling the set of buttons (extraneous load; cf. Paas & Sweller, 2014) eventually exceeded learners' working memory capacities (cf. Paas et al., 2003). All in all, static pictures combined with self-paced design and spoken narration seemed to be particularly demanding for the group of highly developed visualizers. Is it the result of too much cognitive effort applied not only in simply retrieving information but also in deeper comprehension? Did highly developed visualizers, in contrast to less developed visualizers, overestimate their skills in processing pictures and involved themselves in unsuccessful trials of creating a mental model? The learning material was displayed for a certain and rather short time, which might have made this particularly difficult. This doctoral project does not have any certain answers to these questions yet, but it has confirmed that there is a clear relation between learning outcome, type of design and cognitive style. The eye-tracking study conducted as part of this doctoral project provided even more evidence to this relation (see section 7.3).

7.3. Cognitive style and gaze behavior

In spite of critical voices (e.g., Kirschner & van Merriënboer, 2013) the very existence of visual-verbal cognitive style has gained new evidence (e.g., Mehigan et al., 2011; Tsianos et al., 2009). The first study of this doctoral project has also contributed in this regard, showing that individuals with strongly pronounced visual or verbal cognitive style display different gaze behaviors. Namely, when confronted with a stimulus consisting of static pictures and written text, visualizers inspect pictures significantly longer than verbalizers, while verbalizers spend more time on texts than visualizers. This result is in line with previous research (Mehigan et al., 2011; Tsianos et al., 2009). Interestingly, this gaze pattern occurred regardless of the topic of the presented stimulus, the type of knowledge it depicts, and its level of difficulty. This result provides even stronger evidence of cognitive style's impact on learning when considering that learning from picture/ text combinations is heavily driven by text (Hannus & Hyönä, 1999; Rayner et al., 2001, Schmidt-Weigand et al., 2010), hence visualizers' gaze behavior seems to be especially affected by their cognitive style.

The analysis of gaze behavior of participants conducted in the first study of this project revealed that both visualizers and verbalizers displayed an integrative way of learning but within their preferred parts of stimuli. That is to say they were frequently switching between pictures (visualizers) or texts (verbalizers) in order to integrate information from them (cf. Mason et al., 2013b). When confronted with pictorial parts of stimuli though, verbalizers entered the irrelevant areas of pictures sooner than visualizers, which might indicate that verbalizers, as individuals preferring to process information with usage of the verbal channel (cf. Jonassen & Grabowski, 1993; Mayer & Massa, 2003), could generally not be considered experts on pictures. In other words, visualizers, more than verbalizers experienced in using pictorial information, seem to know better than verbalizers *where* to look, when inspecting pictures in order to learn from them.

Additionally, the study showed that visualizers outperformed verbalizers on comprehension tasks (there were no significant differences between both groups of participants on retention tasks). As the material used in this study consisted of series of static pictures and written text, the results are in line with the study of Höffler et al. (2010) and with results of the second study of this doctoral project. In both mentioned studies, highly developed visual style accompanied better learning outcomes in static pictures/ written text condition. This result supports the ability-as-compensator hypothesis (cf. Höffler & Leutner, 2011; Mayer & Sims, 1994) as well, showing that a high level of visual cognitive style may be an important prerequisite in acquiring knowledge from static pictures. It also refers back to the dual-coding theory of Paivio (1986) and the cognitive theory of multimedia learning (Mayer, 2003a, 2008). That is, as visualizers are kind of experts in pictures and able to fully profit from them, the learning material requiring more visual processing (static pictures and written text; cf. Jonassen & Grabowski, 1993; Mayer & Massa, 2003) is not too cognitively demanding for them. That makes visualizers result better than verbalizers on learning outcome when learning from static pictures and written text. Interestingly, this difference occurs only in comprehension tasks, which shows, that, although both groups (visualizers and verbalizers) performed comparably well on retention, only visualizers were able to learn deeper. One can argue that verbalizers were too cognitively overloaded to learn meaningfully, in contradiction to visualizers (cognitive load theory; Sweller, 1994, 1999). All in all, the first study of this doctoral project confirmed the differences between visualizers and verbalizers not only on the text/ picture combinations' viewing patterns but also on the depth of comprehension and, consequently, learning outcome.

7.4. Summary

The results of this doctoral project confirmed that visual-verbal cognitive style exists and plays an important role when learning with multimedia. There are no universally beneficial designs though, as both animations and static pictures, written and spoken text, as well as system- and self-pacing may be advantageous to learners in some cases.

The doctoral project could again confirm the modality effect, as the spoken modality of explanatory text was more beneficial to learners than the written modality (second study; with system paced presentation of the learning material). When addressing the question regarding the superiority of animations over static pictures and self-pacing over system-pacing, it turned out that such effects occur in relation to the type of modality of the explanatory text. Namely, at least when studied with spoken text modality (third study), animation was more beneficial to learners, and, interestingly, the system-paced learning condition yielded better learning outcomes than the self-paced one, not the opposite.

Most importantly, this doctoral project provided more evidence regarding visual-verbal cognitive style. Namely, visualizers and verbalizers differed in the way of looking at stimuli as well as they differed on learning outcomes. When using written text modality, higher cognitive visual style accompanied better learning outcomes in the static pictures condition. On the other hand, the higher the level of visual cognitive style was, the poorer was the learning outcome in the written text/ animation condition (second study). This interaction of visual cognitive style and type of visualization occurred in the written text/ system-paced learning environment, as system-paced design seemed to fit better to spoken, not written explanatory text. The results show additionally that learners with highly developed visual cognitive style are able to manage better when learning with such a design, which is particularly demanding for the visual mental channel (static pictures and written text in a system-paced environment; second study), but perform poorly when confronted with static pictures and spoken text in a self-paced environment (third study). The intensity of *verbal* cognitive style, however, does not seem to play an important role in multimedia learning.

CHAPTER 8

THEORETICAL AND PRACTICAL IMPACT

As mentioned in the previous chapter, the results of this doctoral project contribute to a better understanding of several theoretical constructs. Firstly, they give an input to the discussion on cognitive style, as the eye-tracking study provided clear evidence for the existence of a visual-verbal cognitive style showing that visualizers and verbalizers observe multimedia materials in different ways. That is to say that visualizers strongly rely on pictorial information, whereas verbalizers rely on textual information. Even more, some results suggest that verbalizers are less efficient when using pictures as a source of information, redirecting their point of focus towards irrelevant parts of them too soon. Such empirical results support the assumption that individuals process information using distinct mental channels (dual-coding theory: Paivio, 1978, 1986; cognitive theory of multimedia learning: Mayer, 2008), but verbalizers process information more efficiently with the verbal channel, visualizers with the visual channel (Mayer & Massa, 2003). The research conducted for this doctoral thesis confirms that it has an impact not only on gaze patterns but also on learning outcome.

Secondly, the results show that some theoretical assumptions or hypotheses, originating from research on spatial ability and prior knowledge, can be applied to research on visual-verbal cognitive style. Namely, the expertise reversal effect (Kalyuga, 2007, 2008) as well as the ability-as-compensator hypothesis (Mayer & Sims, 1994) provide plausible explanations for results obtained by learners with higher visual cognitive style, as for example better learning outcome in static picture/ written text condition or worse results in animation/ written text condition. They provide also additional information to previous research indicating that such a pattern of results occurs in condition with written explanatory text (cf. Höffler et al., 2010).

Thirdly, the results support the modality effect (Mayer, 2008), as, in the second study, spoken modality of the explanatory text resulted in better learning regardless of the type of visualization and the intensity of cognitive style of learners. Even more evidence regarding this effect was found in the third study. The comparison of self- and system-controlled learning designs accompanied by a spoken narration supported the assumption of Tabbers (2002) stating that spoken narration gives better results in system-paced multimedia environments. On the other hand, the results of previous research pointing out that self-pacing is especially advantageous when learning with animations were not confirmed (cf. Höffler & Schwartz, 2011).

Finally, the results of this doctoral project may be interpreted by referring to the cognitive load theory (Paas & Sweller, 2014), as static pictures with written text seem to promote learning in individuals with higher cognitive visual style but cause cognitive overload in the group of learners with less pronounced visual cognitive style. On the other hand, static pictures accompanied by a spoken narration may cause cognitive overload in the group of highly developed visualizers when combined with self-paced design. Is it a result of a non-typical design (static pictures + narration + self-pacing) and unsuccessful trials of deep learning in this group of participants, caused by overestimating own skills in processing pictures? The answer to this question is not clear yet.

From a practical point of view, the results of the three studies contribute to the knowledge regarding multimedia design issues. It turned out that both static pictures and animations may bring advantages to learners under certain circumstances. Hence, the assumption of overall supremacy of animation was not supported (cf. Höffler & Leutner, 2007). When learning from dynamic and non-dynamic multimedia, the modality of the explanatory text and the level of learner control play an important role. That is to say that spoken modality of the explanatory text seems to fit better with system-controlled environments (cf. Tabbers, 2002). All three studies confirmed that learners with more or less developed visual cognitive style, or visualizers and verbalizers, attend multimedia learning materials in different ways. As a consequence, they perform differently on tests measuring learning outcome. Thus, when designing multimedia materials, as well as constructing learning environments, the results of research concerning visual-verbal cognitive style should be taken into account. Learners view learning materials and process information differently. Adjusting learning materials to learners' abilities and cognitive skills will result in better learning outcomes.

8.1. Limitations

Every research has some limitations, and this doctoral project is not free of them either. Firstly, when considering the results one should remember that visual-verbal cognitive style is a dimension, thus many individuals show both visual and verbal cognitive style to some extent. It is more difficult to find learners with more pronounced verbal cognitive style than learners with more pronounced visual style though (cf. Cao & Nishihara, 2012). Hence, the absence of significant interactions of verbal cognitive style and different designs of learning materials may result from too low numbers of participants with highly developed verbal cognitive styles.

Secondly, although achieved results were considered in frames of several theories, there are many questions which are still open. For example, why did highly developed visualizers perform worse when confronted with static pictures with spoken narration and self-paced environment? The answer could be more adequate if the real usage of control buttons in self-paced condition had been controlled showing not only the intensity of the usage but also its manner. Additionally, dividing learning environments into several segments, easy to find and play again, would have made using self-pacing easier and more predictable. Moreover, this research project, as focused on the role of cognitive style in multimedia learning, provided only minimal information regarding cognitive load experienced by participants. More detailed insight into levels of experienced cognitive load, as well as the type of it (extraneous, intrinsic, germane load), could have provided useful information and help to understand the results even better.

Finally, some limitations regarding the eye-tracking study concern the level of precision of the eye-tracker employed in it. Namely, it was not possible to compare relevant and non-relevant areas of textual parts of stimuli, as it was the case in pictorial parts of them. As a result, the level of proficiency displayed by verbalizers when retrieving information from texts could not be assessed.

8.2. Conclusions

The doctoral project consisted of three studies which have shed more light on the impact of the visual-verbal cognitive style on learning outcome when learning with computer-based multimedia. Generally, results of the studies contributed to better understanding of learning with dynamic (animations) and non-dynamic (static pictures) visualizations with spoken or written modality of the explanatory text, including a moderating role of cognitive style. Additionally, the issues of learner control and gaze behavior were observed.

Results received in all studies are mostly in line with previous research but also add some new information. That is to say, the eye-tracking data not only strongly supported the existence of a visual-verbal cognitive style but showed that the gaze pattern typical for visualizers and verbalizers is independent from the topic, its difficulty and the type of knowledge it provides. The results of the second and third study did not support the thesis of an overall advantage of animations over static pictures indicating more complex relations. It turned out that static pictures may be more advantageous for participants with higher visual cognitive style but only when the design of learning material is system-paced and the modality of the explanatory text is written. At the same time, participants with higher visual style may perform worse when the modality of the explanatory text accompanying static pictures is spoken and combined with a self-paced environment. The spoken modality proved to be more advantages to learners but when combined with system-paced design.

Thus, it would be recommended to continue the research on visual and verbal cognitive styles and its impact on learning with different types of multimedia learning environments. Future research should address the issue of learner control more systematically, for example by introducing several levels or types of self-pacing, with and without segmentation. Such an approach combined with a more detailed measurement of cognitive load and eye-movements (the latter by usage of a more precise eye-tracker) may help to shed more light on results from, for instance, the third study of this project. The absence of significant effects involving the verbal cognitive style also calls for investigation, for example by conducting studies on purposive samples.

All in all, the present research contributes to better understanding of the impact of visual-verbal cognitive style (cf. Paivio, 1986; Mayer, 2008; Mayer & Massa, 2003) on learning as well as the nature of the modality effect (Mayer, 2008; Tabbers, 2002), the expertise reversal effect (Kalyuga, 2008), and the ability-as-compensator hypothesis (Mayer & Sims, 1994), and provides a valuable input to educational research. The main question of this doctoral thesis “does cognitive style make a difference” seems to find a positive answer. The consequences of different types of visualization and modalities for learning outcome in relation to visual and verbal cognitive styles are still not fully clarified and need further investigation.

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LIST OF TABLES AND FIGURES

10.1. Tables

10.2. Figures

APPENDICES

Appendix A. Visualizers versus verbalizers: Effects of cognitive style on learning with texts and pictures - An eye-tracking study. Means and standard deviations of all transformed variables in the first study.

Variables	Toilet cistern		Learned helplessness	
	M	*SD*	*M*	*SD*
Dwell time – pictures (in ms)	77453.56	27858.03	37782.86	16463.04
Dwell time – texts (in ms)	64917.35	27797.06	45115.53	16423.12
Entry time – irrelevant (in ms)	21438.32	12588.15	22315.25	10794.60
Entry time – relevant (in ms)	27028.86	11182.94	5451.95	3061.61
Transitions across pictures (number)	32.81	16.87	25.78	13.98
Transitions across texts (number)	6.19	5.83	7.28	5.96
Transitions between pictures and texts (number)	34.38	13.94	22.22	9.04
Retention*	.83	.20	.68	.19
Comprehension*	.60	.23	.35	.26

*The scale ranged from 0 to 1.

Appendix B. Visualizers versus verbalizers: Effects of cognitive style on learning with texts and pictures - An eye-tracking study. Instruments and materials used in the first study.

B.1. Telephone interview

Bitte geben Sie die auf Sie zutreffenden Antworten an.

In einer Lernsituation werden Informationen manchmal verbal (z.B. mit geschriebenen oder gesprochenen Wörtern) oder visuell (z. B. mit Bildern, Grafiken oder Animationen) vorgestellt. Was würden Sie bevorzugen?	Die visuell vorgestellte Informationen	Die verbal vorgestellte Informationen
Um einen Prozess zu verstehen, stelle ich mir die einzelnen Schritte bildhaft vor.	JA	NEIN
Ich denke oft in Bildern.	JA	NEIN
Um eine Aufgabe zu lösen, stelle ich mir ihren Inhalt bildlich vor.	JA	NEIN
Ich benutze oft bildliche Vorstellungen, um mir Dinge zu merken.	JA	NEIN
Was bevorzugen Sie zum Lernen?	visuelles Material	verbales Material
Sind Sie ein visueller Lerner („Visualisierer“) oder verbaler Lerner („Verbalisierer“)?	Visualisierer	Verbalisierer
Ich bin gut darin, mit Hilfe von beschrifteten Bildern, Graphen, Landkarten und Animationen zu lernen.	JA	NEIN
Ich bin gut darin, mit Hilfe von geschriebenem Text zu lernen.	JA	NEIN
Wenn Sie etwas jemandem erklären müssen, tun Sie dies bevorzugt mit Hilfe von Bildern oder Graphen?	JA	NEIN
Wenn Sie etwas jemandem erklären müssen, tun Sie dies bevorzugt mit Hilfe von Wörtern?	JA	NEIN
Stellen Sie sich die Handlung gerne vor, wenn Sie ein Buch lesen?	JA	NEIN
Wenn Sie ein Auto fahren und am Telefon sprechen, können Sie leicht wahrnehmen, was auf der Straße passiert?	JA	NEIN
Wenn ich sage „die Rose“, sehen Sie ein Bild oder ein Wort im Kopf?	JA	NEIN

B.2. Verbal-Visual Learning Style Rating (VVLSR, Mayer & Massa, 2003)

	Viel mehr verbal als visuell	Mäßig mehr verbal als visuell	Etwas mehr verbal als visuell	Zu gleichen Teilen verbal und visuell	Etwas mehr visuell als verbal	Mäßig mehr visuell als verbal	Viel mehr visuell als verbal
In einer Lernsituation werden Informationen manchmal verbal (z.B. mit geschriebenen oder gesprochenen Wörtern) oder visuell (z. B. mit Bildern, Grafiken oder Animationen) vorgestellt. Bitte kreuzen Sie an, was Sie bevorzugen würden.	π	π	π	π	π	π	π

B.3. Individual Differences Questionnaire, the visual scale (IDQ, Paivio & Harshman, 1983)

Bitte kreuzen Sie die auf Sie zutreffenden Antworten an

	trifft nicht zu	trifft etwas zu	trifft ziemlich zu	trifft völlig zu
Um einen Prozess zu verstehen, stelle ich mir die einzelnen Schritte bildhaft vor.	π	π	π	π
Ich denke oft in Bildern.	π	π	π	π
Um eine Aufgabe zu lösen, stelle ich mir ihren Inhalt bildlich vor	π	π	π	π
Ich benutze oft bildliche Vorstellungen, um mir Dinge zu merken	π	π	π	π

B.4. Santa Barbara Learning Style Questionnaire (SBCSQ, Mayer & Massa, 2003)

Bitte kreuzen Sie die auf Sie zutreffenden Antworten an:

	Stimmt vollkommen	Stimmt weitgehend	Stimmt eher	Teils-teils	Stimmt eher nicht	Stimmt weitgehend nicht	Stimmt gar nicht
Ich bevorzuge zum Lernen visuelles Material	π	π	π	π	π	π	π
Ich bevorzuge zum Lernen verbales Material	π	π	π	π	π	π	π
Ich bin ein visueller Lerner („Visualisierer“)	π	π	π	π	π	π	π
Ich bin ein verbaler Lerner („Verbalisierer“)	π	π	π	π	π	π	π
Ich bin gut darin, mit Hilfe von beschrifteten Bildern, Graphen, Landkarten und Animationen zu lernen	π	π	π	π	π	π	π
Ich bin gut darin, mit Hilfe von geschriebenem Text zu lernen	π	π	π	π	π	π	π

B.5. Vividness of Visual Imagery Questionnaire (VVIQ, Marks, 1973)

Bitte beurteilen Sie die Klarheit und Anschaulichkeit jedes Bildes anhand folgender Skala:

1	2	3	4	5
Vollkommen klar und anschaulich wie beim tatsächlichen Sehen	Klar und einigermaßen anschaulich	Mäßig klar und anschaulich	Vage und schemenhaft	Überhaupt kein Bild vor Augen (bloß „wissend“, dass Sie über das Objekt nachdenken)

1.) Denken Sie an einen Verwandten oder Freund/Freundin, den/die Sie oft sehen, und betrachten Sie sorgfältig das Bild, das Sie im Geiste sehen. Dann beurteilen Sie folgende Eigenschaften:

a. Die genauen Konturen des Gesichts, Kopfes, der Schultern und des Körpers ☐

b. Charakteristische Kopfhaltungen, Körpersprache, etc. ☐

c. Die genaue Körperhaltung, Schrittlänge etc. beim Gehen ☐

d. Die verschiedenen Farben mancher typischer Kleidungsstücke. ☐

2.) Stellen Sie sich einen Sonnenaufgang vor. Betrachten Sie sorgfältig das Bild, das Sie im Geiste sehen. Dann beurteilen Sie folgende Eigenschaften:

a. Die Sonne steigt über den Horizont hinein in einen verschleierten Himmel. ☐

b. Der Himmel klart auf und umgibt die Sonne mit einem tiefen Blau. ☐

c. Wolken. Ein Sturm kommt auf, Blitze zucken. ☐

d. Ein Regenbogen erscheint. ☐

3.) Stellen Sie sich die Frontansicht eines Ladens vor, in den Sie oft gehen. Betrachten Sie sorgfältig das Bild, das Sie im Geiste sehen. Dann beurteilen Sie folgende Eigenschaften:

a. Die Gesamtansicht des Ladens von der gegenüberliegenden Straßenseite. ☐

b. Ein Schaufenster inklusive der Farben, Formen und Details einzelner Waren. ☐

c. Sie sind nun nahe dem Eingang. Die Farben, Form und Details der Tür. ☐

d. Sie betreten den Laden und gehen zur Kasse. Die Verkäuferin/der Verkäufer bedient Sie. Geld wechselt den Besitzer. ☐

4.) Stellen Sie sich schließlich eine ländliche Szene vor, die Bäume, Berge und einen See beinhaltet. Betrachten Sie sorgfältig das Bild, das Sie im Geiste sehen. Dann beurteilen Sie folgende Eigenschaften:

a. Die Konturen der Landschaft. ☐

b. Die Farben und Formen der Bäume. ☐

c. Die Farben und Form des Sees. ☐

d. Ein starker Wind bewegt die Bäume und verursacht Wellen auf dem See. ☐

B.6. Verbalizer-Visualizer Questionnaire (VVQ, Richardson, 1977)

Bitte kreuzen Sie die auf Sie zutreffenden Antworten an

	Stimmt	Stimmt nicht
Mir machen Arbeiten Spaß, bei denen der Einsatz von Sprache notwendig ist.	π	π
Meine Tagträume sind manchmal so anschaulich, dass es sich anfühlt, als würde ich es tatsächlich erleben.	π	π
Mir macht es Spaß, neue Wörter zu lernen.	π	π
Ich bin gut darin, Synonyme für Wörter zu finden.	π	π
Meine Vorstellungskraft ist höher als beim Durchschnitt.	π	π
Ich träume selten.	π	π
Ich lese eher langsam.	π	π
Wenn ich meine Augen schließe, gelingt es mir nicht, ein mentales Bild des Gesichts eines Freundes zu erzeugen.	π	π
Ich glaube nicht, dass irgendjemand „in Bildern denkt".	π	π
Ich ziehe es vor, eine Anleitung von etwas zu lesen, anstatt dass mir jemand zeigt, wie es geht.	π	π
Meine Träume sind extrem klar und anschaulich.	π	π
Ich kann besser mit Wörtern umgehen als der Durchschnitt.	π	π
Meine Tagträume sind eher undeutlich und verschwommen.	π	π
Ich wende sehr wenig Zeit dafür auf, meinen Wortschatz zu vergrößern.	π	π
Meine Gedanken beinhalten oft mentale Bilder.	π	π

B.7. Object-Spatial Imagery and Verbal Questionnaire (OSIVQ, shortened version, Blazhenkova & Kozhevnikov, 2009)

Bitte kreuzen Sie die auf Sie zutreffenden Antworten an

	1 Stimme über-haupt nicht zu	2	3 Teils-teils	4	5 Stimme voll-kommen zu
In der Schule war ich sehr gut in dreidimensionaler Geometrie.	π	π	π	π	π
Ich habe Schwierigkeiten, mich schriftlich auszudrücken.	π	π	π	π	π
Architektur interessiert mich mehr als Malerei.	π	π	π	π	π
Meine Vorstellungen und inneren Bilder sind sehr klar und farbenreich.	π	π	π	π	π
Beim Lesen eines Fachbuchs ziehe ich schematische Diagramme und Skizzen farbigen Bildern und Illustrationen vor.	π	π	π	π	π
Ich kann Witze und Geschichten besser als die meisten erzählen.	π	π	π	π	π
Das Schreiben von Essays fällt mir schwer und macht mir keinen Spaß.	π	π	π	π	π
Beim Lesen z.B. eines Romans formt sich in der Regel ein klares und detailliertes inneres Bild der beschriebenen Szene oder des Raumes.	π	π	π	π	π
Ich kann mir problemlos dreidimensionale Objekte vorstellen und im Geiste rotieren.	π	π	π	π	π
Meine verbalen Fähigkeiten sind hervorragend.	π	π	π	π	π
Wenn ich über ein abstraktes Bauwerk nachdenke, stelle ich mir eher ein abstraktes schematisches Bauwerk oder einen Plan statt eines spezifischen wirklichen Gebäudes vor.	π	π	π	π	π
Meine Vorstellungen und inneren Bilder sind sehr anschaulich und photographisch.	π	π	π	π	π
Beim Erklären gebe ich lieber verbale Erläuterungen statt Zeichnungen oder Skizzen anzufertigen.	π	π	π	π	π
Meine mentalen Bilder verschiedener Objekte ähneln sich in Größe, Form und Farbe sehr stark tatsächlichen Objekten, die ich gesehen habe.	π	π	π	π	π
Wenn ich mir das Gesicht eines Freundes vorstelle, sehe ich ein vollkommen klares und helles inneres Bild.	π	π	π	π	π
Ich bin sehr gut im Technischen Zeichnen.	π	π	π	π	π
Wenn ich mich an ein bestimmtes Erlebnis erinnere, nutze ich eher verbale Beschreibungen statt innerer Bilder.	π	π	π	π	π
Ich kann mich problemlos an viele visuelle Details erinnern, die anderen nicht einmal auffallen. Z.B. registriere ich automatisch Dinge wie die Farbe des Pullovers oder der Schuhe, die jemand trägt.	π	π	π	π	π
Es fällt mir leicht, eine Skizze oder Aufriss eines Gebäudes, das ich gut kenne, zu zeichnen.	π	π	π	π	π
In der Schule hatte ich keine Probleme mit Geometrie.	π	π	π	π	π
Manchmal sind meine Vorstellungen und inneren Bilder so klar und langlebig, dass es schwer fällt, sie zu ignorieren.	π	π	π	π	π
Ich kann meine Augen schließen und mir problemlos eine erlebte Szene vorstellen.	π	π	π	π	π

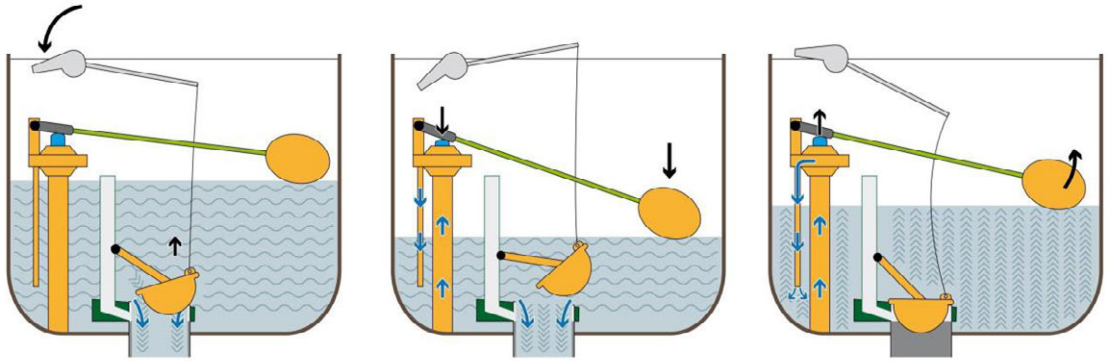
Ich kann mich sprachlich besser ausdrücken als der Durchschnitt.	π	π	π	π	π
Ich bin mir jederzeit der Satzstruktur bewusst.	π	π	π	π	π
Mir macht es Spaß, meine Gedanken in vielerlei Weise sowohl schriftlich als auch mündlich zu variieren.	π	π	π	π	π
Ich erinnere alles visuell. Ich kann mich wahrscheinlich besser daran erinnern, was Leute zum Abendessen trugen, wie sie saßen und aussahen, als daran, was sie erzählten.	π	π	π	π	π
Ich habe manchmal Schwierigkeiten darin, exakt auszurücken, was ich sagen möchte.	π	π	π	π	π
Mir fällt es schwer, mir vorzustellen, wie genau eine dreidimensionale Figur aussehen würde, wenn sie rotiert wird.	π	π	π	π	π
Meine inneren Bilder sind jederzeit in meinem Kopf, genau dort.	π	π	π	π	π
Meine graphischen Fähigkeiten würden eine Karriere als Architekt relativ leicht fallen lassen.	π	π	π	π	π
Wenn ich einem Radiomoderator zuhöre, den ich noch nie gesehen habe, stelle ich mir üblicherweise vor, wie er wohl aussieht.	π	π	π	π	π

B.8. Questions measuring prior knowledge on the topics

1. Haben Sie eine Idee, wie der Spülkasten einer Toilette funktioniert? Beschreiben Sie bitte den Vorgang so gut und kurz es geht.

2. Haben Sie eine Vorstellung davon, was der Ausdruck *Erlernte Hilflosigkeit* bedeutet? Bitte beschreiben Sie dies kurz.

B.9. Learning materials: the toilet cistern set

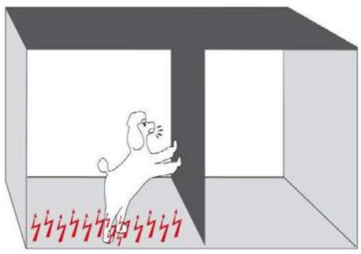


Durch Drücken auf einen Hebel wird ein Verschluss nach oben geöffnet und das Wasser strömt durch ein Rohr heraus.

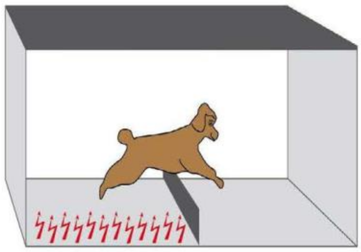
Mit dem Wasserspiegel sinkt ein Schwimmer – je weniger Wasser, desto tiefer befindet er sich. Dabei drückt er über einen Hebel auf ein Ventil an einer Düse.

Loslassen des Hebels verschließt das Rohr wieder. Gleichzeitig wird durch die Düse der Kasten wieder mit Wasser gefüllt, bis der mit dem Wasserspiegel ansteigende Schwimmer das Ventil wieder schließt.

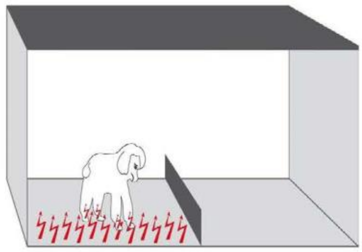
B.10. Learning materials: the learned helplessness set



Ein Hund wird in einen Käfig gesetzt, in dem er unvermeidbaren Stromstößen ausgesetzt ist.



Ein zweiter Hund wird in einen zweigeteilten Käfig mit Barriere gesetzt, über die er springen und so die Stromstöße vermeiden kann, was er auch tut.



Wenn später der erste Hund im zweigeteilten Käfig ist, springt er nicht über die Barriere. Er bleibt hilflos stehen.

B.11. Posttest: Retention questions

Functioning of a toilet cistern:

	Wahr	Falsch
Sobald der Schwimmer eine gewisse Höhe erreicht hat, wird das Ventil nicht mehr gedrückt, so dass neues Wasser aus der Leitung nachströmen kann.	π	π
Loslassen des Hebels verschließt das Rohr wieder.	π	π
Je voller der Spülkasten ist, desto tiefer befindet sich der Schwimmer.	π	π
Sobald der Schwimmer eine gewisse Höhe erreicht hat, wird das Ventil nicht mehr gedrückt, so dass kein Wasser aus der Leitung nachströmen kann.	π	π
Je leerer der Spülkasten ist, desto tiefer befindet sich der Schwimmer.	π	π
Loslassen des Hebels öffnet das Rohr wieder.	π	π

The learned helplessness:

	Wahr	Falsch
Der erste Hund bleibt hilflos stehen, weil er konditioniert wurde, den Stromschlag auszuhalten.	π	π
Ein zweiter Hund springt über die Barriere und erhält dort Stromstöße.	π	π
Ein Hund wird in einen Käfig gesetzt, in dem er vermeidbaren Stromstößen ausgesetzt ist.	π	π
Der erste Hund bleibt hilflos stehen, weil er auf passives Verhalten konditioniert wurde.	π	π
Ein Hund wird in einen Käfig gesetzt, in dem er unvermeidbaren Stromstößen ausgesetzt ist.	π	π
Ein zweiter Hund springt über die Barriere und entgeht so den Stromstößen.	π	π

B.12. Posttest: Comprehension questions

1. Bitte beschreiben Sie jetzt kurz noch einmal, in Ihren eigenen Worten, wie der Spülkasten einer Toilette funktioniert.

2. Bitte beschreiben Sie jetzt kurz noch einmal, in Ihren eigenen Worten, was der Ausdruck *Erlernte Hilflosigkeit* bedeutet.

Appendix C. Does modality play a role? Visual-verbal cognitive style and learning with static pictures versus animations. Instruments used in the second study.

C.1. Individual Differences Questionnaire (IDQ, Paivio & Harshman, 1983)

Bitte beurteilen Sie die Aussagen anhand der folgenden Skala

	trifft nicht zu	trifft etwas zu	trifft ziemlich zu	trifft völlig zu
Ich kann mich sprachlich gut ausdrücken.	π	π	π	π
Es fällt mir leicht, Texte zu lesen.	π	π	π	π
Um einen Prozess zu verstehen, stelle ich mir die einzelnen Schritte bildhaft vor.	π	π	π	π
Ich habe häufig Schwierigkeiten, anderen Leuten Dinge mit Worten zu erklären.	π	π	π	π
Ich denke oft in Bildern.	π	π	π	π
Ich lese sehr langsam.	π	π	π	π
Um eine Aufgabe zu lösen, stelle ich mir ihren Inhalt bildlich vor	π	π	π	π
Ich habe oft Ideen, die ich nur mit Schwierigkeiten ausdrücken kann.	π	π	π	π
Ich benutze oft bildliche Vorstellungen, um mir Dinge zu merken	π	π	π	π
Ich kann meine Gedanken gut in Worte fassen.	π	π	π	π

C.2. Verbalizer-Visualizer Questionnaire (VVQ, Richardson, 1977)

Bitte beurteilen Sie die Aussagen anhand der folgenden Skala

	trifft nicht zu	trifft etwas zu	trifft ziemlich zu	trifft völlig zu
Mir machen Arbeiten Spaß, bei denen der Einsatz von Sprache notwendig ist.	π	π	π	π
Meine Tagträume sind manchmal so anschaulich, dass es sich anfühlt, als würde ich es tatsächlich erleben.	π	π	π	π
Mir macht es Spaß, neue Wörter zu lernen.	π	π	π	π
Ich bin gut darin, Synonyme für Wörter zu finden.	π	π	π	π
Meine Vorstellungskraft ist höher als beim Durchschnitt.	π	π	π	π
Ich träume selten.	π	π	π	π
Ich lese eher langsam.	π	π	π	π
Wenn ich meine Augen schließe, gelingt es mir nicht, ein mentales Bild des Gesichts eines Freundes zu erzeugen.	π	π	π	π
Ich glaube nicht, dass irgendjemand „in Bildern denkt“.	π	π	π	π
Ich ziehe es vor, eine Anleitung von etwas zu lesen, anstatt dass mir jemand zeigt, wie es geht.	π	π	π	π
Meine Träume sind extrem klar und anschaulich.	π	π	π	π
Ich kann besser mit Wörtern umgehen als der Durchschnitt.	π	π	π	π
Meine Tagträume sind eher undeutlich und verschwommen.	π	π	π	π
Ich wende sehr wenig Zeit dafür auf, meinen Wortschatz zu vergrößern.	π	π	π	π
Meine Gedanken beinhalten oft mentale Bilder.	π	π	π	π

C.3. Questions measuring prior knowledge on the topic (the primary reactions in photosynthesis)

Es folgen nun einige Fragen zu Ihrem Vorwissen zur Photosynthese. Bitte beantworten Sie sie so genau wie möglich. Bei Fragen mit mehreren Optionen ist jeweils nur eine Möglichkeit richtig. Es ist nicht schlimm, wenn Sie nicht viel wissen.

1. Beschreiben Sie bitte so detailliert wie möglich, was bei den Primärreaktionen der Fotosynthese geschieht.

   ____

   ____

   ____

2. Die Ausgangstoffe für die Primärreaktionen der Photosynthese sind:
   - ☐ Wasser, Sauerstoff, ADP
   - ☐ Kohlenstoffdioxid, NADP+, ADP
   - ☐ Wasser, NADP+, ADP
   - ☐ Wasser, NADPH+H+, ATP

3. Produkte der Primärreaktionen in der Photosynthese sind:
   - ☐ Sauerstoff, ATP, NADPH+H+
   - ☐ Glucose und Wasser
   - ☐ Kohlendioxid und Sauerstoff
   - ☐ NADP+ und ADP

C.4. Questions measuring learning outcome

Es folgen nun Fragen zum soeben dargestellten Inhaltsbereich der Photosynthese. Bei Fragen mit mehreren Optionen ist jeweils nur eine Möglichkeit richtig. Bitte beantworten Sie jede Frage so gut und ausführlich wie möglich.

1. Nennen Sie die am Elektronentransport entlang der Thylakoidmembran beteiligten Proteinkomplexe und Moleküle.

   ____

   ____

   ____

2. Wie viele Elektronen wandern insgesamt bezogen auf ein Molekül Sauerstoff durch die Proteine der Thylakoidmembran?
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4

3. Während der Primärreaktionen der Photosynthese gibt das Wasser seine Elektronen unmittelbar ab an:
   - ☐ Photosystem I
   - ☐ Photosystem II
   - ☐ Kohlenstoffdioxid
   - ☐ NADP+

4. Welcher Prozess findet – bezogen auf eine Molekül Sauerstoff – in den Primärreaktionen der Photosynthese nicht zweifach statt?
   - ☐ Anregung des Photosystems I
   - ☐ Elektronenabgabe des Photosystems II an Plastochinon
   - ☐ Anregung des Photosystems II
   - ☐ Schließen der Elektronenlücke durch Plastocyanin

5. Wie viele Elektronen und Protonen nimmt das Plastochinon jeweils auf?
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4

6. Plastochinon überträgt die Elektronen und Protonen an:
   - ☐ Photosystem I
   - ☐ Photosystem II
   - ☐ Ferredoxin
   - ☐ Cytochrom-Komplex

7. In der Elektronentransportkette folgt nach dem Cytochrom-b6/f-Komplex die Weitergabe der Elektronen an:
   - ☐ Photosystem II
   - ☐ Photosystem I
   - ☐ Plastocyanin
   - ☐ Ferredoxin

8. Was geschieht am Cytochrom-b6/f-Komplex nicht?
   - ☐ Transport von Protonen in das Thylakoidlumen
   - ☐ Aufnahme von Elektronen
   - ☐ Anregung durch Lichtenergie
   - ☐ Abgabe von Elektronen

9. Photosystem I überträgt Elektronen an:
   - ☐ Plastocyanin
   - ☐ Photosystem II
   - ☐ Ferredoxin
   - ☐ Cytochrom-b6/f-Komplex

10. Photosystem I erhält Elektronen von:
    - ☐ Plastocyanin
    - ☐ Photosystem II
    - ☐ Ferredoxin
    - ☐ Cytochrom-b6/f-Komplex

11. Wie viele NADPH+H+ entstehen pro Wassermolekül?
    - ☐ 1
    - ☐ 2
    - ☐ 3
    - ☐ 4

12. Bei welcher Reaktion wird die Protonenkonzentration über der Thylakoidmembran nicht erhöht?
    - ☐ Bildung von NADPH+H+
    - ☐ Protonentransport am Cytochrom-b6/f-Komplex
    - ☐ Elektronentransport am Plastocyanin
    - ☐ Wasserspaltung

13. Welche Reihe gibt die ATP-Synthese richtig wieder?
    - ☐ ADP+Pi → ATP → Elektronentransport
    - ☐ Protonengradient→ ADP+Pi → ATP
    - ☐ Elektronentransport → ATP → ADP+Pi
    - ☐ ATP→ ADP+Pi → Protonengradient

14. Die Ausgangstoffe für die Primärreaktionen der Photosynthese sind:
    - ☐ Wasser, Sauerstoff, ADP
    - ☐ Kohlenstoffdioxid, NADP+, ADP
    - ☐ Wasser, NADP+, ADP
    - ☐ Wasser, NADPH+H+, ATP

15. Welche Reihe gibt den Elektronentransport während der Primärreaktionen der Photosynthese richtig wieder?
    - ☐ Photosystem I → Photosystem II → NADP+
    - ☐ Wasser → Cytochrom-b6/f-Komplex → NADP+
    - ☐ Photosystem II → Photosystem I → Sauerstoff
    - ☐ NADPH+H+→ Ubichinon → Sauerstoff

16. Bei der Elektronentransportkette wird Wasser genutzt um:
    - ☐ ATP zu hydrolisieren
    - ☐ Pi zu reduzieren
    - ☐ NADPH zu oxidieren
    - ☐ Chlorophyll zu reduzieren

17. Bei Dunkelheit nimmt der pH-Wert im Stroma des Chloroplasten von 8,2 auf 7,2 ab. Diese Erscheinung beruht darauf, dass:
    - ☐ im Stroma NADPH+H+ gebildet wird.
    - ☐ ATP gebildet wird, bis der Protonengradient abgebaut ist.
    - ☐ am Photosystem II Wasser gespalten wird.
    - ☐ am Cytochrom-b6/f-Komplex Protonen in den Thylakoidinnenraum befördert werden.

18. Um Unkraut in seinem Garten zu vernichten, setzt ein Kleingärtner das Unkrautvernichtungsmittel DCMU (Dichlorphenoldimethylharnstoff) ein. Diese Verbindung verhindert Elektronenübertragung auf Plastochinon. Die Folgen davon sind:
    - ☐ NADPH+H+ wird noch gebildet, ein Protonengradient wird nicht aufgebaut, die ATP-Synthese kommt zum Erliegen
    - ☐ Die Wasserspaltung am Photosystem II findet nicht mehr statt, NADPH+H+ und ATP werden noch gebildet
    - ☐ NADPH+H+ wird nicht mehr gebildet, am Cytochrom-b6/f-Komplex werden keine Protonen gepumpt, ATP wird nicht mehr gebildet
    - ☐ Die Wasserspaltung am Photosystem II findet statt, ein Protonengradient wird aufgebaut, ATP wird gebildet.

19. Wodurch wird die Energie für den Elektronentransport bei der Atmungskette und bei den Primärreaktionen der Photosynthese geliefert?
    - ☐ Bei den Primärreaktionen der Photosynthese liefert Licht die Energie für den Elektronentransport. Bei der Atmungskette reicht der Energiegehalt von NADH+H+.
    - ☐ Bei der Atmungskette und bei den Primärreaktionen der Photosynthese liefert ein Protonengradient die Energie für den Elektronentransport.
    - ☐ Bei den Primärreaktionen der Photosynthese reicht der Energiegehalt von Wassermolekülen für den Elektronentransport aus. Bei der Atmungskette liefert NADH+H+ die Energie.
    - ☐ Bei den Primärreaktionen der Photosynthese liefert Licht die Energie für den Elektronentransport, bei der Atmungskette der Sauerstoff.

20. Isolierte Chloroplasten und Mitochondrien werden in einem Experiment einem protonenreichen Medium ausgesetzt. Die Protonen können die äußere und innere Chloroplastenhüllmembran passieren. Bei den Mitochondrien gelangen die Protonen nur in den Intermembranraum. Welches der Organellen stellt unter diesen Bedingungen ATP her?
    - ☐ Der Chloroplast
    - ☐ Das Mitochondrium
    - ☐ Der Chloroplast und das Mitochondrium
    - ☐ Weder der Chloroplast, noch das Mitochondrium

Appendix D. Effects of pacing and cognitive style on learning with dynamic and non-dynamic visualizations with narrative explanations. Instruments used in the third study.

D.1. Individual Differences Questionnaire (IDQ, Paivio & Harshman, 1983)

Bitte beurteilen Sie die Aussagen anhand der folgenden Skala

	trifft nicht zu	trifft etwas zu	trifft ziemlich zu	trifft völlig zu
Ich kann mich sprachlich gut ausdrücken.	π	π	π	π
Es fällt mir leicht, Texte zu lesen.	π	π	π	π
Um einen Prozess zu verstehen, stelle ich mir die einzelnen Schritte bildhaft vor.	π	π	π	π
Ich habe häufig Schwierigkeiten, anderen Leuten Dinge mit Worten zu erklären.	π	π	π	π
Ich denke oft in Bildern.	π	π	π	π
Ich lese sehr langsam.	π	π	π	π
Um eine Aufgabe zu lösen, stelle ich mir ihren Inhalt bildlich vor	π	π	π	π
Ich habe oft Ideen, die ich nur mit Schwierigkeiten ausdrücken kann.	π	π	π	π
Ich benutze oft bildliche Vorstellungen, um mir Dinge zu merken	π	π	π	π
Ich kann meine Gedanken gut in Worte fassen.	π	π	π	π

D.2. Verbalizer-Visualizer Questionnaire (VVQ, Richardson, 1977)

Bitte beurteilen Sie die Aussagen anhand der folgenden Skala

	trifft nicht zu	trifft etwas zu	trifft ziemlich zu	trifft völlig zu
Mir machen Arbeiten Spaß, bei denen der Einsatz von Sprache notwendig ist.	π	π	π	π
Meine Tagträume sind manchmal so anschaulich, dass es sich anfühlt, als würde ich es tatsächlich erleben.	π	π	π	π
Mir macht es Spaß, neue Wörter zu lernen.	π	π	π	π
Ich bin gut darin, Synonyme für Wörter zu finden.	π	π	π	π
Meine Vorstellungskraft ist höher als beim Durchschnitt.	π	π	π	π
Ich träume selten.	π	π	π	π
Ich lese eher langsam.	π	π	π	π
Wenn ich meine Augen schließe, gelingt es mir nicht, ein mentales Bild des Gesichts eines Freundes zu erzeugen.	π	π	π	π
Ich glaube nicht, dass irgendjemand „in Bildern denkt“.	π	π	π	π
Ich ziehe es vor, eine Anleitung von etwas zu lesen, anstatt dass mir jemand zeigt, wie es geht.	π	π	π	π
Meine Träume sind extrem klar und anschaulich.	π	π	π	π
Ich kann besser mit Wörtern umgehen als der Durchschnitt.	π	π	π	π
Meine Tagträume sind eher undeutlich und verschwommen.	π	π	π	π
Ich wende sehr wenig Zeit dafür auf, meinen Wortschatz zu vergrößern.	π	π	π	π
Meine Gedanken beinhalten oft mentale Bilder.	π	π	π	π

D.3. Questions measuring the level of experienced cognitive load

Bitte beantworten Sie jede Frage so gut und ausführlich wie möglich.

1. Wie leicht oder schwer war das Lernmaterial zu verstehen?
   - ☐ Sehr, sehr leicht
   - ☐ Sehr leicht
   - ☐ Leicht
   - ☐ Eher leicht
   - ☐ Weder leicht noch schwer
   - ☐ Eher schwer
   - ☐ Schwer
   - ☐ Sehr schwer
   - ☐ Sehr, sehr schwer

2. Bei der Bearbeitung des Lernmaterials war meine mentale Anstrengung:
   - ☐ Sehr, sehr gering
   - ☐ Sehr gering
   - ☐ Gering
   - ☐ Eher gering
   - ☐ Weder gering noch hoch
   - ☐ Eher hoch
   - ☐ Hoch
   - ☐ Sehr hoch
   - ☐ Sehr, sehr hoch

D.4. Questions measuring prior knowledge on the topic (the primary reactions in photosynthesis)

Es folgen nun einige Fragen zu Ihrem Vorwissen zur Photosynthese. Bitte beantworten Sie sie so genau wie möglich. Bei Fragen mit mehreren Optionen ist jeweils nur eine Möglichkeit richtig. Es ist nicht schlimm, wenn Sie nicht viel wissen.

1. Beschreiben Sie bitte so detailliert wie möglich, was bei den Primärreaktionen der Fotosynthese geschieht! Bitte antworten Sie in ganzen Sätzen!

   ____

   ____

   ____

2. Die Ausgangstoffe für die Primärreaktionen der Photosynthese sind:
   - ☐ Wasser, Sauerstoff, ADP
   - ☐ Kohlenstoffdioxid, NADP+, ADP
   - ☐ Wasser, NADP+, ADP
   - ☐ Wasser, NADPH+H+, ATP

3. Produkte der Primärreaktionen in der Photosynthese sind:
   - ☐ Sauerstoff, ATP, NADPH+H+
   - ☐ Glucose und Wasser
   - ☐ Kohlendioxid und Sauerstoff
   - ☐ NADP+ und ADP

D.5. Questions measuring learning outcome

Es folgen nun Fragen zum soeben dargestellten Inhaltsbereich der Photosynthese. Bei Fragen mit mehreren Optionen ist jeweils nur eine Möglichkeit richtig. Bitte beantworten Sie jede Frage so gut und ausführlich wie möglich.

1. Bitte beschreiben Sie nochmals so detailliert wie möglich, was bei den Primärreaktionen der Fotosynthese geschieht! Bitte antworten Sie in ganzen Sätzen!

____

____

____

2. Nennen Sie die am Elektronentransport entlang der Thylakoidmembran beteiligten Proteinkomplexe und Moleküle.

____

____

____

3. Welcher Prozess wird direkt durch die Lichtenergie unmittelbar angetrieben?
   - ☐ Kohlenstofffixierung im Stroma
   - ☐ Reduktion von NADP+
   - ☐ Abgabe eines Elektrons von einem Chlorophyllmolekül an einen Akzeptor
   - ☐ ATP-Synthese

4. Wie viele Elektronen wandern insgesamt bezogen auf ein Molekül Sauerstoff durch die Proteine der Thylakoidmembran?
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4

5. Während der Primärreaktionen der Photosynthese gibt das Wasser seine Elektronen unmittelbar ab an:
   - ☐ Photosystem I
   - ☐ Photosystem II
   - ☐ Kohlenstoffdioxid
   - ☐ NADP+

6. Der in der Photosynthese freigesetzte Sauerstoff stammt aus:
   - ☐ Kohlenstoffdioxid
   - ☐ Kohlenstoffdioxid und Wasser
   - ☐ Glucose
   - ☐ Wasser

7. Welcher Prozess findet – bezogen auf eine Molekül Sauerstoff – in den Primärreaktionen der Photosynthese nicht zweifach statt?
   - ☐ Anregung des Photosystems I
   - ☐ Elektronenabgabe des Photosystems II an Plastochinon
   - ☐ Anregung des Photosystems II
   - ☐ Schließen der Elektronenlücke durch Plastocyanin

8. Wie viele Elektronen und Protonen nimmt das Plastochinon jeweils auf?
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4

9. Plastochinon überträgt die Elektronen und Protonen an:
   - ☐ Photosystem I
   - ☐ Photosystem II
   - ☐ Ferredoxin
   - ☐ Cytochrom-b6/f-Komplex

10. In der Elektronentransportkette folgt nach dem Cytochrom-b6/f-Komplex die Weitergabe der Elektronen an:
   - ☐ Photosystem II
   - ☐ Photosystem I
   - ☐ Plastocyanin
   - ☐ Ferredoxin

11. Was geschieht am Cytochrom-b6/f-Komplex nicht?
   - ☐ Transport von Protonen in das Thylakoidlumen
   - ☐ Aufnahme von Elektronen
   - ☐ Anregung durch Lichtenergie
   - ☐ Abgabe von Elektronen

12. Photosystem I überträgt Elektronen an:
   - ☐ Plastocyanin
   - ☐ Photosystem II
   - ☐ Ferredoxin
   - ☐ Cytochrom-b6/f-Komplex

13. Photosystem I erhält Elektronen von:
   - ☐ Plastocyanin
   - ☐ Photosystem II
   - ☐ Ferredoxin
   - ☐ Cytochrom-b6/f-Komplex

14. Woher kommen die Elektronen unmittelbar, die über das Ferredoxin auf NADP+ übertragen werden?
    - ☐ Aus dem Photosystem I
    - ☐ Aus dem Wasser
    - ☐ Aus dem Photosystem II
    - ☐ Aus dem Cytochrom-Komplex

15. Wie viele NADPH+H+ entstehen pro Wassermolekül?
    - ☐ 1
    - ☐ 2
    - ☐ 3
    - ☐ 4

16. Bei welcher Reaktion wird die Protonenkonzentration über der Thylakoidmembran nicht erhöht?
    - ☐ Bildung von NADPH+H+
    - ☐ Protonentransport am Cytochrom-b6/f-Komplex
    - ☐ Elektronentransport am Plastocyanin
    - ☐ Wasserspaltung

17. Welche Reihe gibt die ATP-Synthese richtig wieder?
    - ☐ ADP+Pi → ATP → Elektronentransport
    - ☐ Protonengradient→ ADP+Pi → ATP
    - ☐ Elektronentransport → ATP → ADP+Pi
    - ☐ ATP→ ADP+Pi → Protonengradient

18. Die Ausgangstoffe für die Primärreaktionen der Photosynthese sind:
    - ☐ Wasser, Sauerstoff, ADP
    - ☐ Kohlenstoffdioxid, NADP+, ADP
    - ☐ Wasser, NADP+, ADP
    - ☐ Wasser, NADPH+H+, ATP

19. Produkte der Primärreaktionen in der Photosynthese sind:
    - ☐ Sauerstoff, ATP, NADPH+H+
    - ☐ Glucose und Wasser
    - ☐ Kohlendioxid und Sauerstoff
    - ☐ NADP+ und ADP

20. Welche Reihe gibt den Elektronentransport während der Primärreaktionen der Photosynthese richtig wieder?
    - ☐ Photosystem I → Photosystem II → NADP+
    - ☐ Wasser → Cytochrom-b6/f-Komplex → NADP+
    - ☐ Photosystem II → Photosystem I → Sauerstoff
    - ☐ NADPH+H+→ Ubichinon → Sauerstoff

21. Welche Voraussetzungen sind für die Primärreaktionen der Photosynthese nicht erforderlich?
    - ☐ Lichtenergie, Chlorophyll
    - ☐ Wasser, NADP+
    - ☐ Kohlenstoffdioxid, Sauerstoff
    - ☐ ADP

22. Was ist der erste Elektronendonator der Lichtreaktionen? Wo landen die Elektronen schließlich?

____

____

23. Die Lichtreaktionen der Photosynthese versorgen den Calvin-Zyklus mit:
    - ☐ CO_2 und ATP.
    - ☐ H_2O und NADPH.
    - ☐ ATP und NADPH.
    - ☐ Zucker und O_2.

24. Wie werden im Photosystem II freie Elektronen gebildet und wie gelangen sie zum Photosystem I? Bitte antworten Sie in ganzen Sätzen.

    ____

    ____

    ____

25. Bei der Elektronentransportkette wird Wasser genutzt um:
    - ☐ ATP zu hydrolisieren
    - ☐ Pi zu reduzieren
    - ☐ NADPH zu oxidieren
    - ☐ Chlorophyll zu reduzieren

26. Was findet bei den Primärreaktionen nicht statt?
    - ☐ Molekularer Sauerstoff wird freigesetzt.
    - ☐ ATP wird gebildet.
    - ☐ NADPH wird gebildet.
    - ☐ CO_2 reagiert mit Ribulose-1,5-bisphosphate (RuBP)

27. Eine zunehmende Protonenzahl kann man an einem sinkenden pH-Wert erkennen. Wie verändert sich der pH-Wert im Thylakoidinnenraum, wenn die Primärreaktionen der Photosynthese ablaufen?
    - ☐ Der pH-Wert wird größer.
    - ☐ Der pH-Wert wird kleiner.
    - ☐ Der pH-Wert wird erst kleiner und dann größer.
    - ☐ Der pH-Wert bleibt gleich.

28. Bei Dunkelheit nimmt der pH-Wert im Stroma des Chloroplasten von 8,2 auf 7,2 ab. Diese Erscheinung beruht darauf, dass:
    - ☐ im Stroma $NADPH+H^+$ gebildet wird.
    - ☐ ATP gebildet wird, bis der Protonengradient abgebaut ist.
    - ☐ am Photosystem II Wasser gespalten wird.
    - ☐ am Cytochrom-b6/f-Komplex Protonen in den Thylakoidinnenraum befördert werden.

29. Um Unkraut in seinem Garten zu vernichten, setzt ein Kleingärtner das Unkrautvernichtungsmittel DCMU (Dichlorphenoldimethylharnstoff) ein. Diese Verbindung verhindert Elektronenübertragung auf Plastochinon. Die Folgen davon sind:
    - ☐ $NADPH+H^+$ wird noch gebildet, ein Protonengradient wird nicht aufgebaut, die ATP-Synthese kommt zum Erliegen
    - ☐ Die Wasserspaltung am Photosystem II findet nicht mehr statt, $NADPH+H^+$ und ATP werden noch gebildet
    - ☐ $NADPH+H^+$ wird nicht mehr gebildet, am Cytochrom-b6/f-Komplex werden keine Protonen gepumpt, ATP wird nicht mehr gebildet
    - ☐ Die Wasserspaltung am Photosystem II findet statt, ein Protonengradient wird aufgebaut, ATP wird gebildet.

30. Wodurch wird die Energie für den Elektronentransport bei der Atmungskette und bei den Primärreaktionen der Photosynthese geliefert?
    - ☐ Bei den Primärreaktionen der Photosynthese liefert Licht die Energie für den Elektronentransport. Bei der Atmungskette reicht der Energiegehalt von NADH+H+.
    - ☐ Bei der Atmungskette und bei den Primärreaktionen der Photosynthese liefert ein Protonengradient die Energie für den Elektronentransport.
    - ☐ Bei den Primärreaktionen der Photosynthese reicht der Energiegehalt von Wassermolekülen für den Elektronentransport aus. Bei der Atmungskette liefert NADH+H+ die Energie.
    - ☐ Bei den Primärreaktionen der Photosynthese liefert Licht die Energie für den Elektronentransport, bei der Atmungskette der Sauerstoff.

31. Vergleichen Sie die ATP-Bildung bei den Primärreaktionen der Photosynthese mit der ATP-Bildung bei der Atmungskette.
    - ☐ Bei der Atmungskette und bei den Primärreaktionen der Photosynthese liefert nur ein Protonengradient die Energie.
    - ☐ Bei der Atmungskette liefert ein Protonengradient die Energie. Bei den Primärreaktionen der Photosynthese ist außerdem ein Membranpotential erforderlich.
    - ☐ Bei der Atmungskette liefern ein Protonengradient und ein Membranpotential die Energie. Bei den Primärreaktionen der Photosynthese liefert nur ein Protonengradient die Energie.
    - ☐ Bei der Atmungskette und bei den Primärreaktionen der Photosynthese liefert ein Membranpotential die Energie.

32. Isolierte Chloroplasten und Mitochondrien werden in einem Experiment einem protonenreichen Medium ausgesetzt. Die Protonen können die äußere und innere Chloroplastenhüllmembran passieren. Bei den Mitochondrien gelangen die Protonen nur in den Intermembranraum. Welches der Organellen stellt unter diesen Bedingungen ATP her?
    - ☐ Der Chloroplast
    - ☐ Das Mitochondrium
    - ☐ Der Chloroplast und das Mitochondrium
    - ☐ Weder der Chloroplast, noch das Mitochondrium

33. Was wäre wenn? Isolierte Chloroplasten können in einer Lösung mit den notwendigen chemischen Komponenten ATP synthetisieren. Sagen Sie voraus, wie sich die Syntheserate ändern würde, wenn man die Membranen der Organellen für Protonen frei durchlässig machte.

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