

ARTICLE

Does modality play a role? Visual-verbal cognitive style and multimedia learning

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Abstract

The study presented in this paper aimed to examine the effect of visual and verbal cognitive style on learning from different types of visualization and modalities of explanatory text. Learning materials in the form of either computer-based animation or a series of static pictures with written or spoken explanations were presented to 197 students. We found that a more developed visual cognitive style was related to a better learning outcome, when learning from a combination of *static pictures and written text*. Higher developed visualizers achieved poorer learning outcomes when learning with *an animation and written text*. The results are partially in line with an ability-as-compensator effect and the expertise reversal effect. Additionally, we found a modality effect as the versions with spoken text provided better results on learning outcome than the versions with written text regardless of the prominence of visual cognitive style. No significant interaction effects were found regarding verbal cognitive style.

KEYWORDS

ability-as-compensator effect, animation, cognitive style, modality effect, static pictures, visualizer

1 | INTRODUCTION

Learning with combinations of visual and verbal information has been a subject of intense research for many years (e.g., Carney & Levin, 2002; Hegarty, Carpenter, & Just, 1996; Mayer, 2014). Although a general beneficial influence of such combined learning has been thoroughly proven (e.g., Mayer, 2017), there are still many open questions such as, *what is better* (e.g., animations or static pictures; cf., Höffler & Leutner, 2007) or *under which circumstances* the learning environment works better (e.g., Höffler & Leutner, 2011; Huk, 2006; Kalyuga, 2008; Koć-Januchta, Höffler, Thoma, Prechtel, & Leutner, 2017)? To this effect, a great range of individual learner characteristics has been investigated, among them are spatial ability (Höffler & Leutner, 2011; Huk, 2006) and the visual-verbal dimension (Koć-Januchta et al.,

2017; Massa & Mayer, 2006). Although the research results are somewhat inconsistent and have been criticized in the past (e.g., Coffield, Moseley, Hall, & Ecclestone, 2004; Kirschner & van Merriënboer, 2013; Massa & Mayer, 2006), studies confirm neurophysiological differences between people with different cognitive styles (e.g., Glass & Riding, 1999; Jawed, Amin, Malik, & Faye, 2018; Kraemer, Hamilton, Messing, DeSantis, & Thompson-Schill, 2014; Kraemer, Rosenberg, & Thompson-Schill, 2009; Riding, Glass, Butler, & Pleydell-Pearce, 1997). Moreover, several recent eye-tracking studies have also shown differences in eye-movement patterns between people with higher or lower scores on the visual-verbal dimension (Höffler, Koć-Januchta, & Leutner, 2017; Koć-Januchta et al., 2017; Mehigan, Barry, Kehoe, & Pitt, 2011; Tsianos, Germanakos, Lekkas, Mourlas, & Samaras, 2009). Hence, our study aims to investigate multimedia learning

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systematically, using different types of visual (animations or static pictures) and verbal (written or spoken explanatory text) learning materials. Although there are a number of studies in the literature describing difficulties in adapting learning environments to people's cognitive styles (e.g., Kirschner & van Merriënboer, 2013), we hope to shed more light on the learning processes related to visual/verbal cognitive style and different treatment factors. Considering the growing importance of personalized/adaptive education (cf. Domenech, Sherman, & Brown, 2016; Johnson & Samora, 2016; Zhao & Liu, 2019), our study might contribute to a deeper understanding of learning processes, which in turn might improve educational practice.

2 | THEORETICAL BACKGROUND

2.1 | Multimedia learning

The term *multimedia learning* can be defined as learning situations where information is presented to a student in more than one mode, for example, visually and verbally (Mayer, 2014). Combining words and pictures in learning materials promotes comprehension and results in better learning outcomes than learning from words alone (e.g., Carney & Levin, 2002; Hegarty et al., 1996; Mayer, 2014; for a review, see, e.g., Butcher, 2014). The beneficial impact of 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).

Mayer's (2014) cognitive theory of multimedia learning does not explicitly differentiate between different types of pictorial representation, namely, static pictures and animations. Results of a meta-analysis (Höffler & Leutner, 2007) show that the impact of these two types of pictorial representations on learning outcome is not the same and should be studied separately. According to this meta-analysis, animations have the potential to contribute to a better learning outcome than static pictures (overall mean effect size $d = .37$). However, there are other reports suggesting that static pictures minimize extraneous processing and support germane processing (Mayer, Hegarty, Mayer, & Campbell, 2005). Therefore, animations are not necessarily better learning materials (e.g., Tversky, Morrison, & Bétrancourt, 2002) and may enhance cognitive load (Hegarty, 2004).

Thus, the question is not as simple as whether pictures or animations result in better learning outcomes, but rather under what circumstances. Mayer (2008) defined principles for learning with multimedia that concern ways of constructing multimedia environments to help learners overcome cognitive overload. Among these, the *modality principle* plays an important role and states that presenting computer-based pictorial material with spoken explanatory text (instead of written text) makes the learning material easier to comprehend. Interpreting pictures (particularly animated pictures) and reading on-screen text at the same time can be too demanding for the learner's visual channel (in which, text is processed at least initially) and may lead to cognitive overload (Mayer, 2008). In contrast, when learning

simultaneously from pictures and narration, learners can use the visual channel for processing pictures and the auditory (verbal) channel for processing text. Doing so may result in better learning outcomes because working memory resources are used more efficiently, which prevents cognitive overload (Baddeley, 1992; Mayer, 2008; Mayer, Dow, & Mayer, 2003; Mayer & Moreno, 2003; Moreno & Mayer, 1999, 2002). However, there are some evidence 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 to split attention between text and pictures, as learners listen to the narration and view the pictures at the same time (Liu, Lin, Gao, & Paas, 2018; Tabbers, 2002).

Another interesting contribution to this discussion is made by Tabbers, Martens, and van Merriënboer (2001) who compared system-paced (when the speed of the presentation is defined by the system) and self-paced (when the learner has at least some influence over the speed of presentation) 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, whereas the self-paced condition yielded the opposite result—the written text condition was more beneficial for learners than the spoken text condition (Tabbers et al., 2001). 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. As our study applies only system-paced learning materials, the inclusion of another possible factor, in the form of visual-verbal cognitive style, might shed a new light on these findings.

2.2 | The visual-verbal dimension of cognitive information processing

The visual-verbal dimension of cognitive information processing derives from the dual-coding theory (Paivio, 1986) and states that information is processed and mentally represented in distinct channels: visual and verbal (Cuevas & Dawson, 2018). Both mental representations are used when selecting, organizing, integrating, storing, and retrieving information. Research on the basis of Paivio's theory shows that some people prefer the verbal channel (verbal learners), whereas others prefer the visual channel (visual learners) when processing information (cf. Güray, 2016; Jonassen & Grabowski, 1993; Mayer & Massa, 2003; Pashler, McDaniel, Rohrer, & Bjork, 2009). Clear differences in eye movements in groups of participants scoring high or low on questionnaires measuring the visual-verbal dimension confirm differences in attentional patterns between visualizers and verbalizers (cf. Koć-Januchta et al., 2017; Mehigan et al., 2011; Tsianos et al., 2009), as eye movements and gaze are related to one's intensity and direction of attention (e.g., Bucher & Schumacher, 2006; Duchowski, 2007).

A notable challenge that is faced when designing a study on the visual-verbal dimension is the great inconsistency in the literature as to whether the visual-verbal dimension should be treated as a cognitive style (e.g., Alhathli, Masthoff, & Beacham, 2018; Richardson, 1977), as a learning preference (e.g., Leutner & Plass, 1998; Plass,

Chun, Mayer, & Leutner, 1998), or as a learning style (e.g., Kirby, Moore, & Schofield, 1988; Lu & Yang, 2018). 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 (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.

A further challenge regarding visual-verbal cognitive style is an inconsistency regarding its structure. In this regard, some researchers claim it is a one-scale dimension with two ends (Mayer & Massa, 2003), whereas others interpret two different scales (e.g., Paivio & Harshman, 1983), or two scales with the visual scale subdivided into an object and spatial subscale (e.g., Haciomeroglu, 2016; Kozhevnikov, Kosslyn, & Shephard, 2005). In this respect, our study aims to shed further clarity on this issue, because in the case of a one-dimensional structure of visual-verbal cognitive style, we could expect that verbal cognitive style would play a comparable but inverse role in multimedia learning in comparison with visual cognitive style. Put differently, if the one-dimension structure is true, people with high scores on the verbal cognitive style scale would learn similarly to less developed visualizers.

The current state of research on visual-verbal cognitive style and multimedia learning leaves us with more questions than answers. For example, when and under which circumstances are animations superior to static pictures? When is the opposite true? What is the role of the modality effect? In a study by Höffler, Prechtel, and Nerdel (2010), highly developed visualizers learned better with static pictures than with animations, whereas 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. Albeit so, work by Höffler and Schwartz (2011) yielded different results. In their study, learners tending toward a visual cognitive style performed better on a learning outcome test when learning from animations, whereas learners tending toward a verbal cognitive style performed better when learning from static pictures. We hypothesize that the contradictory results in the studies of Höffler et al. (2010) and Höffler and Schwartz (2011) may be a result of the different modalities (written versus spoken) of explanatory texts that were used.

In Höffler et al. (2010), highly developed visualizers performed better in the static pictures condition (a more difficult learning design or a “poorer” design). Hence, the results partially support the *ability-as-compensator* hypothesis, which states that a high level of ability enables overcoming problems of a poor instructional design (cf. Höffler &

Leutner, 2011). However, this pattern of results does not fully align with the pattern of the ability-as-compensator effect, because contradictory to expectations, highly developed visualizers performed worse with animations than with static pictures on deeper comprehension tasks. The latter result connotes an *expertise reversal effect*, which occurs when more experienced learners that learn from instructional material that is more suitable for novices are hindered from optimal performance (Kalyuga, 2007). Höffler et al.'s (2010) results are somewhat analogous to this effect as a highly developed visual style helped people to better learn from static pictures (more difficult learning design) but was a hindrance when learning with animations (simpler learning design).

Regarding these unclear patterns and somewhat contradictory results, our study addresses the following research questions:

- Because 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 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?
- In addition, the study by Tabbers et al. (2001) showed that spoken modality was especially beneficial when combined with system-paced learning environments. As our study was designed with system-pacing only, does visual or verbal cognitive style prove to be a relevant factor in this effect? We expected differences in learning outcome especially in the written-text condition, as this condition should be more demanding for learners due to the necessity to split attention between text and pictures (Tabbers, 2002). Lastly, we aimed to contribute to the discussion about the structure of visual-verbal cognitive style.

3 | METHOD

3.1 | Participants

Participants were 197 students (74.1% females) between 18 and 35 years of age ($M = 21.68$; $SD = 2.40$) enrolled mainly in biology majors at Kiel University. Because there were more females than males in the sample, we strived to have comparable percentages of female participants in each of four conditions (versions) of the learning environment (from 72.9% to 76% females in each condition). Additionally, we checked whether there were any significant differences between males and females on the main study variables (prior knowledge, visual-verbal cognitive style questionnaires scores: see later). This was not the case (all $p > .12$). Moreover, as the findings of Campos (2014) show that men and women differ mostly on spatial imagery and image rotation performance tests, whereas there are mostly no differences between genders on imagery questionnaires—similar to those we used in our study—we decided to continue analyses with this sample.

All participants voluntarily participated in the study and signed a consent form. Each participant was rewarded with 12 EUR in acknowledgement of their participation.

3.2 | 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 primary reactions in photosynthesis (see Figure 1). Each version of the learning environment lasted 10 min 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 piloted before the experiment with a group of 30 biology students. This pilot study helped us to determine that the learning material should be demonstrated twice in order to obtain better learning outcomes and to choose 20 well-differentiating post-test questions. The learning environment was noninteractive by design—participants did not have opportunity to control (e.g., stop or fast-forward/rewind) the visualized learning environment.

3.3 | Measures and instruments

Taking into account controversies and inconsistencies in the literature, we decided to use two of the most common questionnaires measuring visual-verbal cognitive style—the Individual Differences Questionnaire, IDQ (Paivio & Harshman, 1983) and the Verbalizer-Visualizer Questionnaire, VVQ (Richardson, 1977)—as a basis for a new questionnaire. We calculated four scores as the means of the IDQ and VVQ items, two

verbal and two visual scores. Next, we performed a principal component analysis (oblimin rotation) on these four scores. The analysis showed that the four scores loaded on two factors, a visual and a verbal factor, respectively (variance accounted for: 79%). We used the two factors as new visual and verbal scales that indicated the prominence of visual and verbal cognitive style (Cronbach's α : $\alpha = .78$ and $\alpha = .86$, respectively).

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 ($\alpha = .70$). Examples of questions measuring prior knowledge and learning outcome are shown in Table 1.

Tables 2 and 3 present descriptive statistics and inter-correlations for all study variables.

3.4 | Procedure

At first, participants answered several questions on their age, sex, enrolled semester, university major, and GPA in high school (Abitur). Then, the students completed the two questionnaires regarding visual-verbal cognitive style (IDQ, VVQ). After answering three prior knowledge questions, they watched the displayed learning environment twice (20 min). Participants were randomly assigned to one of four conditions (versions). At the end of the study, participants

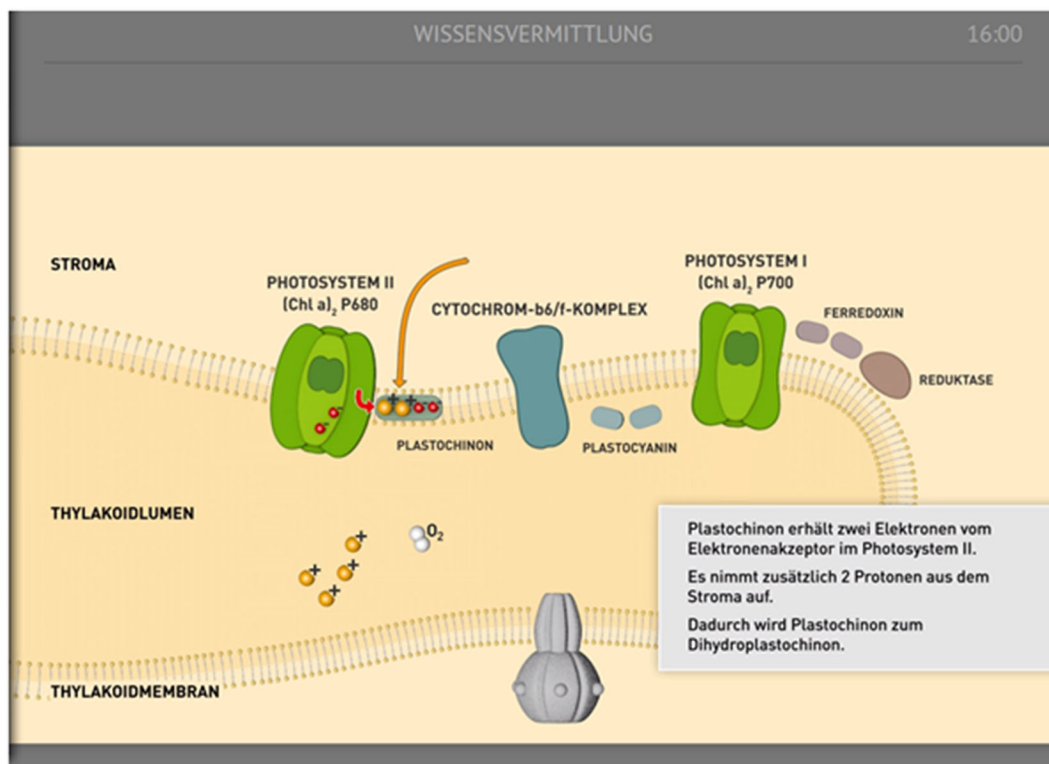


FIGURE 1 Exemplary snapshot of a static picture with written text. The text says: “Plastoquinone receives two electrons from electron acceptor in photosystem II. Additionally, it uptakes two protons from the stroma. As a result, plastoquinone turns into dihydro-plastoquinone.” [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Exemplary items for assessing prior knowledge and learning outcome

Type of assessed knowledge	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:	(1) Oxygen, ATP, NADPH+H+ (2) Glucose and water (3) Carbon dioxide and oxygen (4) NADP+ and ADP
Learning outcome	During the primary reactions of photosynthesis, water delivers its electrons directly to:	(1) Photosystem I (2) Photosystem II (3) Carbon dioxide (4) 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:	(1) NADPH+H+ is still being constructed, the proton gradient is being raised, the ATP synthesis comes to a standstill. (2) The water splitting in the Photosystem II stops, NADPH+H+ and ATP are still being generated. (3) NADPH+H+ is not being generated anymore, no more protons are being pumped to the cytochrome b ₆ f complex, and ATP is not being generated anymore. (4) The water splitting in the Photosystem II is still on, the proton gradient is being raised, and ATP is being generated.

answered 20 post-test questions. The whole study was computer-based and lasted for about 1 hr.

4 | RESULTS

The analysis of pretest questions showed that participants had little prior knowledge on the topic ($M = 1.18$, $SD = 1.34$, with 10 as the possible maximum).

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 a 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 integrating the predictors into the linear model in the following sequence: (a) the covariates, (b) the treatment factors

and their interaction, (c) the two interactions of cognitive style and each of the treatment factors, and (d) the triple interaction of cognitive style and the two treatment factors. We expected the 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.

4.1 | Visual cognitive style

In analysing visual cognitive style as the covariate, we obtained the expected modality effect, $F(1,185) = 3.60$, p (one-tailed, 1-*df*-test) = $.059/2 = .030$, $\eta^2 = .019$; $M_{\text{spoken}} = 64.65$; $SD_{\text{spoken}} = 15.15$; $M_{\text{written}} = 60.05$; $SD_{\text{written}} = 18.05$. We also yielded the expected triple interaction of visual cognitive style, type of modality, and type of visualization, $F(1,185) = 3.93$, $p = .049$, $\eta^2 = .021$. Table 4 shows the results of all effects of this analysis, and Figure 2 displays the significant triple interaction.

As can be derived from Figure 2, a higher visual cognitive style is coupled with better learning outcomes with static *pictures accompanied by written text*. In contrast, higher visual cognitive style is associated with poorer learning outcomes with *animations accompanied by*

TABLE 2 Descriptive statistics for study variables

	<i>M</i> (Mean)	<i>SD</i> (Standard Deviation)	Min.	Max.	Number of items	Cronbach's α
Prior knowledge (Sum of points)	1.18	1.34	0	8.50	3	.50
Learning outcome (Percentage of correct answers)	62.22	16.71	22.50	100.00	20	.70
IDQ Verbal Score (Mean)	3.13	.61	1.33	4.00	6	.82
IDQ Visual Score (Mean)	2.86	.66	1.25	4.00	4	.82
VVQ Verbal Score (Mean)	2.57	.59	1.14	3.71	7	.74
VVQ Visual Score (Mean)	3.04	.51	1.20	4.00	7	.67

Abbreviations: IDQ, Individual Differences Questionnaire; VVQ, Verbalizer-Visualizer Questionnaire.

TABLE 3 Inter-correlations of study variables

	Prior knowledge (Sum of points)	Learning outcome (Percentage of correct answers)	IDQ Verbal Score (Mean)	IDQ Visual Score (Mean)	VVQ Verbal Score (Mean)	VVQ Visual Score (Mean)
Prior knowledge (Sum of points)	—	.382**	-.08	.11	.00	.05
Learning outcome (Percentage of correct answers)	.382**	—	-.03	.12	-.01	.02
IDQ Verbal Score (Mean)	-.08	-.03	—	-.168*	.681**	.05
IDQ Visual Score (Mean)	.11	.12	-.168*	—	-.01	.420**
VVQ Verbal Score (Mean)	.00	-.01	.681**	-.01	—	.198**
VVQ Visual Score (Mean)	.05	.02	.05	.420**	.198**	—

Abbreviations: IDQ, Individual Differences Questionnaire; VVQ, Verbalizer-Visualizer Questionnaire.

**Correlation is significant at the.01 level (two-tailed).

*Correlation is significant at the.05 level (two-tailed).

TABLE 4 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

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 accompanied with *spoken text*. In other words, visual cognitive style correlates positively

with learning outcomes 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, the 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.

4.2 | Verbal cognitive style

Analyzing verbal cognitive style as the covariate generated the expected modality effect, $F(1,185) = 2.92$, p (one-tailed, 1- df -test) = $.089/2 = .045$, $\eta^2 = .016$; $M_{spoken} = 64.65$; $SD_{spoken} = 15.15$; $M_{written}$

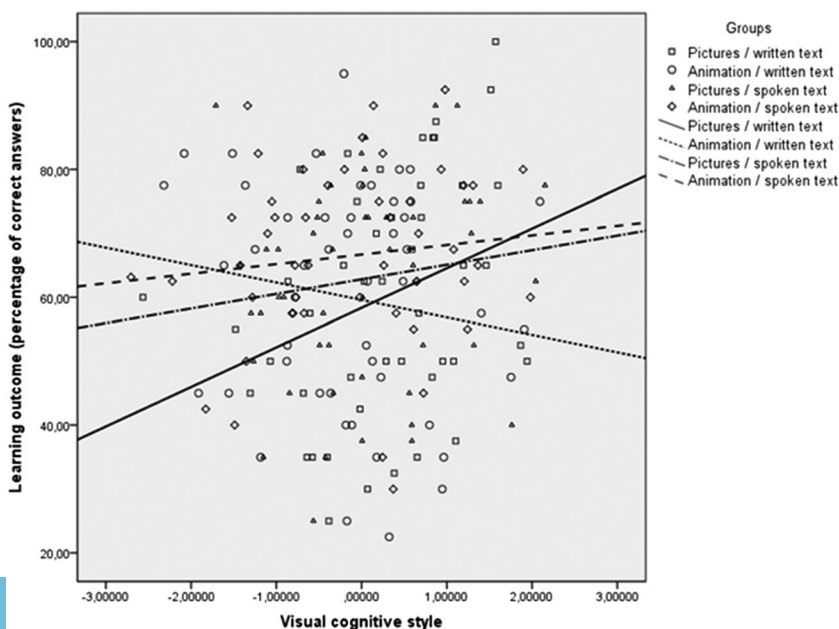


FIGURE 2 Learning outcome (percentage of correct answers) as a function of visual cognitive style, type of visualization, and type of modality.

= 60.05; $SD_{\text{written}} = 18.05$. We did not obtain any other significant interaction effects in the comparable analyses with verbal cognitive style (and GPA) as covariates (all $p > .05$). The results of all the effects of these analyses are provided in Table 5.

5 | DISCUSSION

In the study conducted by Höffler et al. (2010), highly developed visualizers and less developed visualizers learned 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 provided explanatory text. We expected that the highly developed visual cognitive style would compensate for any disadvantages of the poorer (or more difficult) learning design (static pictures) when learning with written text. The use of spoken text should be less demanding for all participants regardless of the intensity of their visual or verbal cognitive style, which is in line with the modality principle (Mayer, 2008), dual-coding theory (Paivio, 1986), and Tabbers et al.'s (2001) findings. To the best of our knowledge, there are no studies systematically comparing static pictures and animations combined with written and spoken explanatory text in the context of visual-verbal cognitive style. That was the additional rationale behind our decision to include modality of the explanatory text to the design.

Visual cognitive style turned out to be an important covariate in our model, and as expected, only in the written text condition. Here, 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 also found that such an effect only occurs in the written text condition. The effect we found might be referred to as a *partial* ability-as-compensator effect, as a more pronounced visual cognitive style accompanies better learning 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 and delivered comparable results for all participants regardless of the multimedia environment (static pictures or animations).

According to dual-coding theory (Paivio, 1986), information is processed in two distinct channels: visual and verbal. The cognitive theory of multimedia learning (Mayer, 2014) claims that processing multimedia materials occurs in two channels across both sensory memory and working memory (Schüler, Scheiter, Rummer, & Gerjets, 2012). Which channel is involved depends first on the sensory modality of the incoming information (auditory vs. visual) and later on the mode of representation of the information in working memory (verbal vs. pictorial). Written text is initially treated as visual image in working memory (Schüler et al., 2012). When a learning environment simultaneously provides two different types of information which both demand—at least to some extent—visual processing (static pictures and explanatory written text in our study), this can lead to difficulties, especially for people who prefer the verbal channel for processing information (cf. Jonassen & Grabowski, 1993; Mayer & Massa, 2003). According to Mayer (2008), their visual mental channel is too overloaded to allow them to benefit from the learning environment.

If the additional information provided by the explanatory text, regardless if written or spoken, is actually verbal, it is still unclear how it is processed. As reading needs initial visual resources, the question arises for how long these visual resources are needed? And does visual cognitive style play a role even at this stage? We can assume that written text is processed visually at the sensory memory stage. But how is it processed in working memory? The interaction found in our research might suggest that the change of channels from visual to auditory occurs in the later stages of processing information and that visual cognitive style is at least related to proceeding information conveyed in written form.

Likewise, the question when and how this switch from one channel to another occurs is far from being clear. Kraemer et al. (2014), using repetitive transcranial magnetic stimulation (rTMS) and fMRI paradigm, propose the conversion hypothesis, namely, that people scoring high on the verbal cognitive style questionnaires have a tendency to code even nonverbal information into the verbal domain. Hence, according to this hypothesis, the way of representing information is not determined by the way how the information was conveyed but more by the learners' characteristics. Why shouldn't the same be true for participants with visual cognitive style?

Additionally, it is important to underline that conducting research on differences between visual and verbal working memory processes is challenging because of the difficulties in controlling or assessing the used strategy. In a recent study by Hilbert et al. (2019), 47 students were examined with repetitive transcranial magnetic stimulation (rTMS) to examine the use of visual processing strategies in the DSB (the digit span backwards task). The results prove the critical importance of the visual cortex for visualizers compared to verbalizers. Furthermore, the results indicate that the preferred cognitive strategy determines the processing modality to greater extent than the presentation modality. Both studies cited above show that visual and verbal proceeding is a complex process, in which not only the modality

TABLE 5 Results of the analysis with verbal cognitive style

Effect	F	df	p	η^2
GPA (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

of the stimulus but also the preferred cognitive strategy play important roles.

An alternative to dual-coding explanation proposes Tabbers's (2002) notion of an attentional effect involved in the modality effect. According to Tabbers, verbal explanations were actually processed through the verbal channel, because interpreting written text only involves visual resources at the initial stage. Considering the necessity to split attention between written text and pictures, there is not enough time to process both modes of information, hence, the visual information can only be processed superficially. Higher developed visualizers, as kind of experts in using and processing visual information, might be able to handle these difficulties better than less developed visualizers. For less developed visualizers, the necessity to deal with two visual information sources, even if only initially, could have been too demanding.

There are also other explanations emphasizing a lack of temporal contiguity in written text–pictures condition, as there is no possibility to process written text and pictures simultaneously (in contradiction to the spoken text; Schüler et al., 2012). All in all, more research is clearly needed on the modality effect and the involved cognitive processes.

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? One possible explanation is the expertise reversal effect (Kalyuga, 2007). In the written text condition, an animation seems to be an obstacle rather than an aid for people with a more pronounced visual style. Is this the case, because the animation, especially a transitory animation, provides a “ready-made” product, which inhibits higher developed visualizers to act in their preferred way, in the form of organizing visual information in the way most suitable for them? When confronted with the animation with written text, do less developed visualizers rely simply on one of the two visual sources: either on the written text alone or on the animation alone? Such an interpretation would be in line with results from the study of Schnotz and Rasch (2005), which suggested that animations can provide too much help for high prior knowledge learners. Animations were found to hinder such learners from processing information on their own. Is this also the case for higher developed visualizers?

Another possible explanation would be in line with Riding and Adams (1999), who observed that visual learners processed text slower than verbal learners. Visual learners had longer response times because they were generating mental images of the written words. Perceiving a transient animation while creating mental images of written words at the same time could exceed working memory capacity. Does this mean that generating mental images of spoken words is easier or less time-consuming for these students?

As the analyses of 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 state any assumption concerning a compensatory effect for people with a high verbal cognitive style. Nevertheless, the lack of any significant effects on verbal cognitive style has provided additional evidence for

understanding visual and verbal cognitive styles as two independent dimensions. As our study was predominantly focused on visual processing, verbal cognitive style did not play a significant role in the research. We can only assume 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 in the written form.

Overall, participants showed better learning outcomes when learning with spoken text than when learning with written text, which is in line with the modality principle (Mayer, 2008) and Tabbers (2002). In this regard, interpreting a transient learning environment accompanied by a spoken narration does not require splitting attention between written text and pictures.

6 | CONCLUSIONS AND IMPLICATIONS FOR LEARNING AND INSTRUCTIONAL DESIGN

In response to the research question whether cognitive style interacts not only with the type of visualization but also with the type of modality, the triple interaction effect shown in our study suggests that the visual cognitive style and its influence plays an important moderating role when learning with animations or static pictures with written text.

Additionally, we might conclude that the modality effect can be considered as a treatment factor that enhances learning with static pictures and animations and leads to comparably good learning outcomes regardless of cognitive style. By way of this reasoning, highly developed visual style can be considered as a compensator when learning with static pictures and written text (cf. Huk, 2006; Kalyuga, 2008). In comparison with our findings, the results of Höffler et al. (2010) take on a new meaning. Our study confirms that the effect found by Höffler et al. (2010) is moderated by the presentation modality of the verbal explanation. It is still open to debate whether this effect is due more to an attentional effect, to cognitive overload, or if we can link it to other cognitive processes. Thus, our study could be perceived as a valuable starting point inspiring future studies aimed to investigate the interplay of visual and auditory channels in processing written text and the role of visual-verbal cognitive style, modality effect and attention in it, as well as higher-level cognitive functions.

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 that may be associated with the expertise reversal effect (Kalyuga, 2007). Alternatively, creating mental images of written words while perceiving an animation could exceed working memory capacities of higher developed visualizers (cf. Riding & Adams, 1999). Interestingly, this effect does not occur when learning with an animation in combination with 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.

There are various implications of our research for learning and instructional design. First, cognitive styles seemingly do exist and have an impact on learning. This finding can be especially interesting in relation to the use of AI in learning. Personalized educational platforms can make learning environments more flexible when answering learners' needs and characteristics (e.g., Johnson & Samora, 2016). Second, the modality of the explanatory text has an impact on learning outcome. This suggests that the written mode should be especially applied with caution, because it is negatively related to learning outcome of higher developed visualizers. One possible method to overcome this shortcoming could be to offer students a set of multimedia learning environments to choose from. Another possibility is to design an adaptive, personalized learning environment.

7 | LIMITATIONS AND FUTURE RESEARCH

One limitation of our study is the unbalanced sample that contains more females than males. However, any reference concerning gender differences and imaging ability must take into account the type of imagery and the measurement instrument used (Campos, Pérez-Fabello, & Gómez-Juncal, 2004). As we have used questionnaires instead of performance tests, we could assume that no considerable gender differences influenced our results (cf. Campos, 2014; Campos et al., 2004). In any case, such an unbalanced sample might be considered highly ecologically valid, because more women than men study biology at universities in Germany. Nevertheless, future research conducted on a balanced sample would be desirable.

Our study did not yield significant results regarding the verbal cognitive style, which, on one hand, seems to confirm the two-dimensional structure of visual-verbal cognitive style but, on the other hand, also raises new questions—especially, if the verbal cognitive style plays a role while learning from text-picture combinations. If so, what type of role and under which circumstances? The problem might also stem from 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. Overall, future studies should be performed with previously selected, gender-balanced groups of highly developed verbalizers and less developed verbalizers in order to shed more light on their learning behavior.

Also of high interest are questions regarding a hindering effect of animations with written text in the group of highly developed visualizers, and the absence of such an effect in the animation and spoken text condition. Does this serve as an example of an expertise reversal effect (Kalyuga, 2007)? Is it related to creating mental images by visualizers (Riding & Adams, 1999)? Further studies might provide further insight about these questions.

Lastly, in order to clarify the effect of visual cognitive style with written text but not with spoken text, it would be interesting to design a study that includes a general resource-consuming task in the learning situation. In this respect, a secondary task that engages executive control resources or working memory, could help investigate possible explanations of this effect.

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CONFLICT OF INTEREST

The authors declare that no conflict of interest exists.

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