17 The Signaling (or Cueing) Principle in Multimedia Learning

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INTRODUCTION TO THE SIGNALING OR CUEING PRINCIPLE IN MULTIMEDIA LEARNING

The signaling principle, also known as the cueing principle, refers to the finding that people learn more deeply from a multimedia message when cues are added that guide attention to the relevant elements of the material or highlight the organization of the essential material (Alpizar, Adesope, & Wong, 2020; Mayer, 2021; Richter, Scheiter, & Eitel, 2016; Schneider, Beege, Nebel, & Rey, 2018; see also Chapter 14). The signaling or cueing principle can be particularly crucial for the first step in multimedia learning according to the Cognitive Theory of Multimedia Learning (Mayer, 2021; see also Chapter 5): *selecting* information. In order to learn from multimedia materials, information needs to be attended to in order to be available for processing in working memory.

What information will be attended to is determined both by bottom-up and top-down processes. Bottom-up means that the characteristics of the learning material partly determine what aspects draw attention; for instance, regarding visual attention it has been shown that visually salient features generally draw novices' attention (Lowe, 1999, 2003). Top-down means that knowledge of the task, or instructions provided, also determine what aspects receive attention. In his classic eye-tracking study, Yarbus (1967) showed that instructions affect visual attention (i.e., viewing patterns) during picture observation.

Regarding knowledge of the task, it has been shown that with increasing knowledge of a task, individuals tend to allocate visual attention faster and proportionally more to task-relevant information. This has been found in a variety of domains, for instance when comparing experts and novices in chess (Charness, Reingold, Pomplun, & Stampe, 2001), driving (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003), and classification of movement patterns in biology (Jarodzka, Scheiter, Gerjets, & van Gog, 2010). There are also indications that it occurs between individuals with smaller differences in expertise, for instance in troubleshooting simulated electrical circuits (van Gog, Paas, & van Merriënboer, 2005). Moreover, this effect has been found *within* individuals over time as a result of practice (Haider & Frensch, 1999) or instruction (Canham & Hegarty, 2010; Hegarty, Canham, & Fabrikant, 2010).

In multimedia learning, this means that the attention allocation of novices, who lack prior knowledge of a task, may rely more on the characteristics of the stimulus material. That is, they are likely to pay much attention to perceptually salient features (Lowe, 1999, 2003), even though these may not always be the most relevant for the task at hand. Processing information that is not relevant for learning induces extraneous cognitive load that is ineffective for learning or may even hamper learning (Sweller, Ayres, & Kalyuga, 2011; see also Chapter 6). Moreover, when the learning materials are dynamic and transient, attending to salient but less relevant information automatically means that relevant information may not be attended to promptly and, thus, may no longer be available for processing (de Koning, Tabbers, Rikers, & Paas, 2009). Since both processing less relevant information and not processing relevant information will be deleterious for learning, it is necessary to guide learners' attention to the essential material, which can be achieved by means of signaling or cueing.

Thus, the signaling or cueing principle is particularly crucial for the first step of *selecting* information, and, presumably, especially for novice learners. However, it may also aid in the other steps necessary for successful multimedia learning: *organization* and *integration* of information. That is, signaling or cueing may not only prevent extraneous load by preventing processing of less relevant information, but may simultaneously foster germane load, by facilitating the organization or integration of essential material.

EXAMPLES OF SIGNALING OR CUEING IN MULTIMEDIA LEARNING

Cues come in many forms and can be incorporated in the text, the picture, or both. Text-based cues can consist of sentences that precede the learning materials and highlight

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their organization (e.g., Mautone & Mayer, 2001, experiment 1) or of sentences that are inserted into the text to guide attention to the picture (e.g., Hayes & Reinking, 1991), or they can be more subtle, drawing attention to certain key terms or ideas by using color in written text (e.g., Moreno & Abercrombie, 2010) or intonation in spoken text (e.g., Mautone & Mayer, 2001, experiment 3).

Picture-based cues can consist, for instance, of arrows (e.g., Boucheix & Lowe, 2010; Lin & Atkinson, 2011), in which case they are extrinsic in the sense that an element is added to the picture. Cues can also be more intrinsic, for instance, by changing the color of elements in the picture (e.g., Jamet, Gavota, & Quaireau, 2008) or their labels (e.g., Ozcelik, Arslan-Arib, & Cagiltay, 2010), or by flashing elements (Jeung, Chandler, & Sweller, 1997) when they are being referred to in spoken text. Another way to enhance visual saliency without adding information is by shading everything but the element that is being referred to (e.g., de Koning, Tabbers, Rikers, & Paas, 2010b). Finally, by zooming in at relevant elements, peripheral information that is not relevant at that moment is no longer visible (Amadieu, Mariné, & Laimay, 2011).

As for cueing both text and picture: in color coding, corresponding elements of the text and picture are connected by giving them the same color (e.g., Kalyuga, Chandler, & Sweller, 1999). In the next section, the main findings from research on the signaling or cueing principle in multimedia learning are reviewed.

WHAT DO WE KNOW ABOUT THE SIGNALING PRINCIPLE IN MULTIMEDIA LEARNING?

Given the focus on multimedia learning, a discussion of research on the effects of signaling or cueing in learning materials that are solely text-based and do not include explanatory pictures, such as *expository text* (e.g., Loman & Mayer, 1983; Lorch & Lorch, 1995, 1996; Lorch, Lorch, & Klusewitz, 1995; Mayer, Dyck, & Cook, 1984; Sung & Mayer, 2012), *lectures* (e.g., Scerbo, Warm, Dember, & Grasha, 1992; Titsworth & Kiewra, 2004), *matrices* (e.g., Jairam, Kiewra, Kauffman, & Zhao, 2012), or *Web menus* (e.g., Rouet, Ros, Goumi, Macedo-Rouet, & Dinet, 2011), or learning materials that are solely picture-based and do not include explanatory text, such as *animations* (e.g., Amadieu, Mariné, & Laimay, 2011; Boucheix & Lowe, 2010; Boucheix, Lowe, Putri, & Groff, 2013; de Koning, Tabbers, Rikers, & Paas, 2007, 2010a, 2011; Fischer & Schwan, 2010; Lowe & Boucheix, 2011) or *graphs* (e.g., Mautone & Mayer, 2007; Shah, Mayer, & Hegarty, 1999), fall outside the scope of this chapter. Moreover, this chapter does not focus on social cues, such as gaze direction or gestures that may be provided by instructors or animated pedagogical agents in video/animated lessons, as these are reviewed in Chapters 23 and 38.

In the rest of this section, empirical research on the effects of incorporating cues in (1) the text, (2) the picture, or (3) both (i.e., cueing corresponding text-picture elements) is reviewed, followed by (4) a review of research on the effects of using cues based on successful people's eye movements.

Text-Based Cues

Several studies investigated the effects of signaling by providing a short text indicating the main steps in the process prior to the main explanatory text, and then emphasizing the steps in the explanatory text. For instance, Harp and Mayer (1998) studied the effects of signaling that consisted of providing students with preview sentences that listed the main steps in the process that was explained and depicted (lightning formation) as well as numbering the steps, in conditions with and without seductive details. Overall, there was no significant effect of signaling on retention or transfer, but focusing on only the conditions without seductive details, cueing seems to have a small-to-medium effect on retention (d = .23) and transfer (d = .33). Mautone and Mayer (2001) investigated signaling in spoken text (yes/no) and in an animation (yes/no). Only the results of a comparison of the spoken text signaling in the uncued animations are discussed here; for the effects of providing cues in the animation, please refer to the next subsection. They found that signaling consisting of a preview summary and emphasizing the structure of explanatory spoken text that accompanied an animation, by manipulating intonation and emphasis improved transfer (d = .70; see also Mayer, 2021).

Next to providing signals prior to studying and emphasizing the structure of the materials (i.e., the steps), it also seems to be effective to cue key terms in the text. For example, Moreno and Abercrombie (2010, experiment 2) investigated the effects of signaling key terms (by using red font) in worked-out solutions that followed teaching situation cases consisting of either written text or animations. They found a significant positive main effect of signaling on transfer performance for the text (d = .63) and the animation conditions (d = .85) as well as significantly lower perceived cognitive load for the signaled groups.

Other studies have investigated the use of explicit verbal cues in the text to foster the integration of information from text and picture. Hayes and Reinking (1991) investigated the effects of explicit verbal cues in the text that directed learners' attention to a picture that was redundant with the text (i.e., provided the same information), with or without adjunct study material. These cues had no effects on comprehension test performance, but had a positive effect on performance on a multiple choice test that assessed learning from the redundant picture, at least when combined with adjunct study material (control versus cues: poor readers d = .16, good readers d = .10; control versus adjunct materials: poor readers d = .58, good readers d = .31; control versus combined: poor readers d = 1.48, good readers d = .91). A similar form of verbal cueing was studied

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by McTigue (2009), who also used explicit verbal cues in the text to direct attention to the corresponding element in the picture (e.g., "Look again at the diagram, at number 6, to see where steam is turned to water," p. 146), which did not improve learning outcomes.

Picture-Based Cues

Picture-based cues can be used in both static and dynamic pictures to guide attention to the relevant elements when they are mentioned in segmented written text or in spoken text (for reviews of cueing in dynamic visualizations, see de Koning & Jarodzka, 2017; de Koning, Tabbers, Rikers, & Paas, 2009). For instance, Tabbers, Martens, and van Merriënboer (2004) investigated the effects of color cues in a lesson on instructional design that was almost an hour long. The lesson consisted of 11 diagrams with which either written text or spoken text was presented. The text presented with each diagram was divided into fragments, and after reading or hearing each fragment students could click a *next* button to go to the next text fragment. In the cueing conditions, the part of the diagram that the text fragment referred to was colored red. There was a significant effect of cueing on retention test performance (d = .32), but not on transfer, nor on invested mental effort in the learning phase, retention test, or transfer test. There was no interaction between cueing and text format.

In multimedia learning materials with narrated text, Jamet, Gavota, and Quaireau (2008) investigated the effects of cueing by means of color changes. In a multimedia lesson on brain areas involved in language production, students heard a spoken explanation and saw a picture with the relevant brain areas being labeled and colored gray, either all from the start (static) or gradually after being referred to in the text (sequentially). In the cueing conditions, the areas turned red while they were referred to in the narration. There was a significant positive effect of cueing on process retention (d = .59), on function retention (d = .58), and on picture completion (d = .46), but not on transfer. Perceived ease of use was higher in the cued conditions (d = .54). They found no significant interactions with static versus sequential presentation.

Ozcelik, Arslan-Arib, and Cagiltay (2010) used a similar type of cue in multimedia materials that explained how a jet engine works. In an otherwise static picture, a verbal label changed color (i.e., turned red) for the duration of the sentence when that element was mentioned in the narration, after which it changed back to black. They found that total fixation duration on relevant labels and picture elements was higher in the color-coding condition, but average fixation duration did not differ (because of the increased number of fixations on relevant areas). There were no differences between conditions on the retention test, but there was a significant positive effect of color coding on a matching test and transfer test.

Instead of using colors, de Koning, Tabbers, Rikers, and Paas (2010b) shaded all elements of the animation except for the element that was being referred to in the narration or that learners had to self-explain (i.e., one group got spoken instructional explanations, the other group had to generate explanations). Cueing had a significant beneficial effect on performance on retention (d = .75), inference (d = 1.24), and transfer test questions (d = 1.17). There was no significant interaction, suggesting that cueing was equally effective for both conditions.

Mautone and Mayer (2001) used a combination of several cues in an animation on how airplanes fly accompanied by narrated text: arrows, color, and summary icons. Comparing the cued and uncued animation conditions with text signaling, there was a beneficial effect of cueing on transfer (d = .60; see also Mayer, 2021).

Using arrow cues in static or dynamic pictures with spoken text, Lin and Atkinson (2011) did not find a beneficial effect of cueing on learning outcomes, but they did find that cueing reduced learning time and was therefore more efficient. Investigating arrow cues in animations, Lin, Atkinson, Savenye, and Nelson (2016) did not replicate the effect on learning time, but did find that cueing enhanced learning outcomes (d = .66). While the arrow cues did not affect self-reported cognitive load or motivation compared to no cues, structural equation models did show that cueing changed the relation of those variables with learning outcomes: in the no-cueing condition, cognitive load predicted learning, but motivation did not, whereas in the cueing condition, this was reversed and cognitive load did not, but motivation did impact learning outcomes.

The use of arrow cues was also investigated by Crooks, Cheon, Inan, Ari, and Flores (2012). They used a 2×2 design with written or spoken text and with low or high levels of cueing. They used a text plus picture on articulation in human speech. The text was divided into segments and could be accessed by clicking on markers in the picture, which indicated important locations for articulation in the vocal tract. After clicking, a text box appeared in the written text condition or the text segment was narrated in the spoken text condition. In the low cueing conditions, the markers that were clicked temporarily changed color. In the high cueing condition, the marker that was clicked on changed color and an arrow pointed towards it. They found no effects of cueing on learning outcomes or cognitive load; however, it should be noted that there was no real control condition in the sense that there was some cueing in the low cue condition and moreover, participants accessed the text by clicking on elements in the picture. This is different from, for instance, the Tabbers, Martens, and van Merriënboer (2004), study where the text was also fragmented, but the corresponding picture elements still needed to be identified. As such, in these materials of Crooks, Cheon, Inan, Ari, and Flores (2012), cueing might not have been necessary for facilitating the selection or integration of information.

This would be in line with findings from an early study on the use of picture-based cues with narrated text, in which Jeung, Chandler, and Sweller (1997) established the degree of visual search as a potential pre-condition for the effectiveness of cueing. According to the modality effect (see Chapters 19 and 20), presenting spoken text with pictures should be more effective for learning than written text with pictures. However, Jeung, Chandler, and Sweller (1997) showed that under conditions of high visual search, using spoken text was no more effective than written text, unless cueing was provided (i.e., flashing) that guided attention to the right place at the right time, which had a positive effect on retention (but not on transfer). Under low visual search conditions, spoken text was more effective than written text, and cueing had no additional benefit for learning.

Cueing Corresponding Elements in Written Text and Pictures

To facilitate the integration of written text and static pictures, color-coding can be used to highlight the correspondence between elements of the text and picture by giving them the same color. For instance, Kalyuga, Chandler, and Sweller (1999, experiment 2) used color coding in a learner-controlled manner, in learning materials consisting of a diagram of an electrical circuit and a text about its functioning. When learners clicked on a step in the text, the electrical circuit elements that were mentioned changed into the same color in both the text and the diagram. There was no significant difference between the cueing and the no-cueing conditions on fault-finding performance, but the cueing (color coding) group performed significantly better on multiple choice test items (d = 1.46) and reported lower effort investment during learning (d = .93).

When the text is presented all at once, it is more convenient to use different colors for different elements. Folker, Ritter, and Sichelschmidt (2005) conducted a study on color-coding cues with biology materials on mitosis consisting of written text accompanied by pictures with labels. In the color-coding condition, those words in the text that corresponded to labels had the same color as the labels and the structures in the picture that the labels referred to. In the control condition, the picture had the same colors, but words in the text and labels were not colored. Although they did not find an effect of color-coding cues on learning outcomes, the color-coding group was significantly faster in processing the learning materials, which seemed to be due to a reduction in the number of fixations and the cumulative time spent fixating on the picture (there were no differences between conditions in number of fixations and the cumulative time spent fixating on the text). These findings are very interesting as they provide insight into how color-coding cues might aid the integration of text and graphics. It should be noted, though, that this study had a low number of participants (n = 10 per condition).

With learning materials on synaptic transmission, Ozcelik, Karakus, Kursun, and Cagiltay (2009) studied this type of color-coding cueing in a very similar manner. In their materials, however, the pictures did not contain colored elements; only the verbal labels within the pictures were presented in different colors that matched the colors of those words in the text. They found no differences in study time, but they did find that the time needed to locate the corresponding elements in the text and picture was reduced in the color-coding condition (i.e., when a word in the text was fixated, the amount of time it took for the corresponding label in the picture to be fixated was shorter when the word in the text and the label in the picture had the same color). Average fixation duration, on the other hand, increased. Moreover, participants in the color-coding condition showed better performance on retention and transfer questions, but not on a matching test, in which participants had to match elements of the pictures with verbal labels. Perceived difficulty of the learning materials was also measured, but did not differ between conditions.

More recently, Scheiter and Eitel (2015) investigated effects of signaling on attention and learning, using a multimedia lesson about the circulatory heart system with or without signals that highlighted corresponding text–picture elements. Students who received the cued version attended to the signaled information more often and earlier during learning, and this explained their better performance on test questions that required text-diagram integration. In a second experiment, they replicated these findings, and ruled out that this was simply a consequence of the cues increasing picture processing more generally (by using a third condition in which mismatching elements were highlighted; this guided students' attention initially, but they later ignored those cues).

As mentioned in the introduction, theoretically, one would predict cueing to be particularly necessary for novice learners; advanced learners might be able to locate the right information at the right time based on their prior knowledge, and might therefore not need the cues (partial expertise reversal effect) or the cues might even have a detrimental effect on their learning (full expertise reversal effect; Kalyuga, Ayres, Chandler, & Sweller, 2003; see also Chapter 13). Richter, Scheiter, and Eitel (2018) investigated the influence of prior knowledge on the effects of cueing corresponding elements, with secondary education students who learned from a digital chemistry textbook. Students in one condition received a basic signaling version with either text or picture signals only (e.g., bold face), students in the other condition received an extended signaling version that cued corresponding elements to support text-picture integration (e.g., color-coding). They found a full expertise reversal effect, with low prior knowledge students showing better learning outcomes when corresponding elements were cued (compared to the basic version), whereas this had a detrimental effect on learning for high prior knowledge learners. This was partially explained by cognitive load: high-prior-knowledge learners reported higher extraneous cognitive load when corresponding elements were cued. Using the same materials, Richter and Scheiter (2019) conducted an eye-tracking study with secondary education students. They replicated the finding that cueing corresponding elements was effective for low prior knowledge students' learning; however, in this study, there was only a partial expertise reversal effect, in that cueing corresponding elements did not affect high prior knowledge students' learning. The eye movement data showed that students with low prior knowledge who received the corresponding-elements cues version looked at the picture earlier during studying.

In sum, most studies showed that cueing can have a positive effect on reducing cognitive load (when this was measured) and improving learning outcomes, although effects seem inconsistent across outcome measures. Note that several studies mentioned here not only used learning outcomes as a measure of whether cueing was effective, but also investigated whether it successfully guided learners' visual attention, using eye tracking (see e.g., Folker, Ritter, & Sichelschmidt, 2005; Ozcelik, Arslan-Arib, & Cagiltay, 2010; Ozcelik, Karakus, Kursun, & Cagiltay, 2009). Eye tracking (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & van de Weijer, 2011) allows researchers to study the allocation of visual attention; that is, it can tell us at what elements of a stimulus a participant looked, in what order, and for how long. It is increasingly used for studying visual attention allocation in multimedia learning (van Gog & Scheiter, 2010). Given that cueing is expected to guide attention, eye tracking is well suited and is increasingly used for determining whether cueing was successful at that or not, which is important information that cannot necessarily be derived from learning outcomes. Cueing may be successful at guiding attention but, despite the beneficial effects reported in this section, this does not always lead to higher learning outcomes (e.g., in animations without text: de Koning, Tabbers, Rikers, & Paas, 2010a). Without eye movement data, it would be difficult to determine whether a lack of effect on learning means that the cues were not successful at guiding attention, or whether it is due to another factor (e.g., learners' inability to interpret the information that was cued). However, eye tracking is not only useful for studying whether cues attract attention, it can also play a role in the development of cues.

Cues Based on Others' Eye Movements, and Eye Movements as Visual Cues

Next to the question of what kind of cue to use, an important question for instructional designers is what aspects of the materials should be cued. Mostly, this decision seems to be made based on the designer's own knowledge of the task and its most relevant aspects. Another approach would be to use eye tracking to study differences in attention allocation between more successful and less successful learners or problem-solvers and use this information to decide what to cue.

For instance, Grant and Spivey (2003) conducted an influential study that was strictly speaking not about multimedia learning as it used a diagram only (of Duncker's radiation problem). They showed that guiding attention by visually cueing a diagram area (i.e., the skin) that successful participants fixated prior to finding the solution, led to enhanced insight problem-solving performance compared to cueing another area (the tumor) or no cue. While this effect on insight problem-solving *performance* is interesting, it would be even more interesting if the same applied to multimedia *learning*.

Indeed, Schwonke, Berthold, and Renkl (2009) used a similar approach to improve learning from worked examples on probability calculation that consisted of multiple representations (text, tree diagram, and mathematical equation). They first showed that conceptual understanding after example study was positively associated with more extensive processing (i.e., fixating) of the tree diagrams, and negatively with transitions from text to equations (i.e., skipping the diagrams). This suggested that the diagrams played an important role in learning from the worked examples. Using this insight, they conducted another study in which they provided half of the participants with instruction on tree diagrams and their functional relation to the other representations. This could be conceived of as verbal signaling provided prior to rather than during worked example study. The instruction that signaled the relevance of the tree diagrams had a strong effect on learning that was partially mediated by learners' allocation of visual attention to the diagrams.

In line with the findings by Schwonke, Berthold, and Renkl (2009), Scheiter et al. (2019) also found (in a first experiment) that students who had longer fixations times and higher fixation counts on text and picture, and made more transitions between text and picture when studying illustrated texts, showed better learning outcomes. Based on these findings they developed a gaze-contingent adaptive system that analyzed learners' eye movements in real time and provided visual cueing (e.g., highlighting relations between text and pictures) when needed (e.g., when learners were insufficiently integrating text and picture). Interestingly, this gaze-contingent adaptive system hampered learning of students with lower cognitive prerequisites (i.e., a composite score of general scientific literacy and content-specific prior knowledge) but fostered learning of students with higher cognitive prerequisites compared to a non-adaptive presentation of the illustrated text.

Next to designing cues based on patterns of eye movements, it is also possible to use a replay of an expert or a successful learner's eye movements as a cue. Also using Duncker's radiation problem, Litchfield and Ball (2011) found that showing participants a dynamic 30 second replay of another person's eye movements, in which the skin area was crossed several times, increased

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performance. A similar result was also demonstrated on a visual diagnosis task in medicine (Litchfield, Ball, Donovan, Manning, & Crawford, 2010). Again, these studies focused only on performance, but there is evidence that attention guidance based on eye movement replays can foster learning as well.

Based on the findings discussed at the beginning of this chapter, that individuals with more knowledge of a task look faster and proportionally more at relevant aspects of a task, van Gog (2006) hypothesized that this might have consequences for learning from video-based modeling examples consisting of screen-recordings. In such modeling examples, the learner observes a recording of an experienced model's computer screen while s/he gives a didactical demonstration of the task (with or without a verbal explanation). That is, if the novice does not attend to the same information as the model, learning might not be optimal, for instance because the model's verbal explanation may be difficult to follow when the learner does not know what the model is referring to, or because information in the examples might be transient and the right information needs to be attended to at the right moment or it will be gone and replaced by other information. van Gog (2006) hypothesized that resolving this discrepancy in learner-model attention allocation by showing the learner the model's eye movements in the examples might foster learning (i.e., *eye movement modeling examples*; EMME). Moreover, next to helping the learner process the model's verbal explanation, by displaying the model's eye movements EMME also signal the perceptual task-processing strategy of the model (which would otherwise remain invisible) to learners.

Indeed, EMME have been found to be effective for learning a variety of tasks, for instance, findings show that EMME can be effective for learning to solve geometry problems (van Marlen, van Wermeskerken, Jarodzka, & van Gog, 2018), learning to classify locomotion patterns in biology (Jarodzka, van Gog, Dorr, Scheiter, & Gerjets, 2013), learning to diagnose epileptic seizure symptoms (Jarodzka et al., 2012), or medical images (Gegenfurtner, Lehtinen, Jarodzka, & Säljö, 2017), and for acquiring study strategies such as text-picture integration (Mason, Pluchino, & Tornatora, 2015, 2016; Mason, Scheiter, & Tornatora, 2017; Scheiter, Schubert, & Schüler, 2018) or multiple document integration (Salmerón & Llorens, 2019).

Note, though, that the studies by Jarodzka et al. (2012) and Jarodzka, van Gog, Dorr, Scheiter, and Gerjets (2013) also showed that the way in which eye movements are displayed in the replay (in other words, the way in which the visual cues are designed) might play an important role in the effectiveness of EMME. Moreover, studies in problem-solving suggest that EMME are not effective for learning when learners do not need the guidance provided by the displayed eye movements. This can occur when they can easily infer from other sources (e.g., the verbal explanation or mouse clicks) what the model is referring to (van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009), or because they have sufficient prior knowledge to quickly locate the information the model is referring to. For instance, it was found that for university students who had relatively high prior knowledge, EMME on how to solve geometry problems successfully guided attention (i.e., students looked faster and more often at the information the model was referring to) but did not improve learning compared to regular modeling examples that did not display the model's eye movements (van Marlen, van Wermeskerken, Jarodzka, & van Gog, 2016, 2018). For secondary education students (who had less prior knowledge than the university students), however, EMME did improve learning outcomes (van Marlen, van Wermeskerken, Jarodzka, & van Gog, 2018). Although prior knowledge was not systematically compared within one experiment, these findings again suggest it may be a boundary condition for the effectiveness of signaling/cueing.

IMPLICATIONS FOR COGNITIVE THEORY

Most studies reviewed here showed a beneficial effect of signaling or cueing on learning outcomes, which is in line with the predictions of and provides support for the Cognitive Theory of Multimedia Learning (Mayer, 2021; see also Chapter 5). Indeed, this impression is supported by findings from meta-analyses on text-based, picture-based, and text-picture integration cues (i.e., these meta-analyses did not include studies on eye movements as cues).

A comprehensive meta-analysis by Schneider, Beege, Nebel, and Rey (2018) focusing on many different types of text-based and picture-based cueing, which included 103 studies, overall found positive effects of signaling on learning ($g+ = .53$; 117 out of 139 positive effect sizes), transfer ($g+ = .33$; 55 out of 70 positive effect sizes), cognitive load (i.e., signaling reduced cognitive load; $g+ = .25$; 19 out of 27 positive effect sizes), and motivation/affect ($g+ = .13$; 11 out of 13 positive effect sizes; note this was a quite small effect and small number of comparisons), and a negative effect on learning time (i.e., signaling increased study time; $g+ = -.30$; 20 out of 27 positive effect sizes). Type of signaling was a significant moderator of the effect on learning, with text-based signals resulting in higher effect sizes than picture-based signals. This meta-analysis did not find a moderating effect of prior knowledge.

Interestingly, the meta-analysis by Richter, Scheiter, and Eitel (2016), which was specifically focused on cues that highlight corresponding elements in text and picture, did find a moderating effect of prior knowledge. Twenty-seven studies were included in the meta-analysis, yielding 45 pairwise comparisons. Overall, there were 38 (out of 45) positive effect sizes, yielding a small-to-medium signaling effect in favor of signaled compared to non-signaled multimedia learning material ($r = .17$). Prior knowledge was found to moderate the signaling effect; in line with what one would expect based on the notions

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from Cognitive Theory of Multimedia Learning and Cognitive Load Theory discussed in the introduction to this chapter, low prior knowledge learners did profit from cues that highlighted corresponding elements ($r = .19$), whereas high prior knowledge learners did not (i.e., a slightly negative, albeit non-significant, effect of $r = -.08$).

Thus, signaling or cueing fosters multimedia learning, presumably by helping learners to select, organize, and integrate the information presented in the text and pictures. For cues that help learners connect text and picture and cues that are based on the model's eye movements, learners' prior knowledge would seem to be a boundary condition; these types of cues only seem to foster novices' learning.

Note that the signaling or cueing principle may have some relation with other principles identified by the Cognitive Theory of Multimedia Learning as well. For instance, visually cueing elements of a picture when they are being mentioned in the spoken text, or visually cueing corresponding elements in written text and picture seems to have a close relationship with the split-attention effect or spatial contiguity principle (see Chapters 14 and 15). That is, by color-coding corresponding elements, the integration of separately presented materials can be facilitated (e.g., Folker, Ritter, & Sichelschmidt, 2005). In addition, while presenting the same verbal information both in narration and in writing is known to result in a redundancy effect (see Chapters 14 and 16) and hampers learning, emphasizing only main ideas from a narrated text by presenting them on-screen in writing, seems to have beneficial effects on learning (Mayer & Johnson, 2008), which can be explained by the signaling or cueing principle.

IMPLICATIONS FOR INSTRUCTIONAL DESIGN

The research results reviewed in this chapter show that signaling or cueing can be a powerful tool for instructional designers. Cueing can be implemented to help learners use their limited working memory capacity in an optimal manner, by helping them with selecting, organizing, and integrating the information presented in the text and pictures. However, given the wide variety in cues used and conditions in which cues were used in the research reviewed here, it is hard to distill clear-cut, detailed guidelines for instructional designers regarding when cueing is needed, what elements of the text or picture should be cued, and what type of cue is most useful with what kind of materials.

LIMITATIONS OF CURRENT RESEARCH AND IMPLICATIONS FOR FUTURE RESEARCH

There are several limitations to the present studies that future research could attempt to address. First most studies reviewed here hypothesized that cueing facilitates learning by reducing the amount of visual search required, because the cues guide attention to the right location or to the important information, which should reduce extraneous load that is ineffective for learning and might increase germane load that is effective for learning (see Sweller, Ayres, & Kalyuga, 2011; see also Chapter 6). However, studies that directly measure effects on attention allocation and/or on cognitive load only started to emerge fairly recently. In order to attain a better understanding of the underlying cognitive mechanisms of the cueing effect, it would be desirable if future studies would continue to more systematically investigate effects on attention allocation and on cognitive load.

Second, the studies reviewed here suggest, and the meta-analysis of Schneider, Beege, Nebel, and Rey (2018) seems to confirm, that the type of cue used may affect (the strength of the effect on) learning outcomes. However, because of the many differences between studies in terms of types of cues, types of participants, types of learning materials, et cetera, it is impossible at the moment to provide instructional designers with guidelines on which type of cue to use when. A more systematic (and potentially multi-lab) research program, varying one aspect at a time, would be required to address such questions.

Third, with regard to individual differences, research has thus far primarily focused on prior knowledge, but other variables may be important. For instance, like prior knowledge, working memory capacity may be associated with the cognitive load students experience. Indeed, a study by Skuballa, Schwonke, and Renkl (2012) suggested that individual differences in working memory capacity may play a role in the (in)effectiveness of cueing or signaling. Thus, it seems important for future research to explore the possible role of various individual difference variables in learning from multimedia materials with cues.

Last but not least, little attention has been paid thus far to motivational or affective responses to cues (Schneider, Beege, Nebel, & Rey, 2018). It would be relevant to know more about what types of cueing increase students' motivation, as this may help students stay engaged when they are studying in multimedia learning environments.

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