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# State-of-the-Art Research into Multimedia Learning: A Commentary on Mayer's Handbook of Multimedia Learning

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*Summary: This article reviews the research into multimedia learning through the lens of a recently updated Handbook of Multimedia Learning edited by Richard Mayer. By examining the theories underpinning the research and the major experimental findings, a number of conclusions emerged. Firstly, the major theories and models guiding the research are well accepted and based on classical memory research, although there is a need to extend them to the affective domain. Secondly, most of the boundary conditions for effective learning from basic multimedia materials (e.g. explanatory words and pictures) have been identified. Thirdly, for more complex learning environments (e.g. games and computer-based tutors), much less is known, and more research is required to untangle the various moderating factors. Fourthly, there is a need for further investigations that match specific instructional strategies (e.g. self-explanations) with multimedia materials to find the most effective learning combination.*


## INTRODUCTION

The second edition of the *Cambridge Handbook of Multimedia Learning* edited by Richard Mayer was published in 2014 and consists of 34 chapters written by leading researchers into multimedia learning Mayer (2014a). Together these chapters provide a comprehensive state-of-the-art analysis of the research on multimedia learning. In the 9 years since the first edition (Mayer, 2005), the field has advanced significantly in terms of the depth of research completed. The reviews cover topics ranging from basic multimedia effects such as combining text and diagrams to highly complex systems such as intelligent tutors that incorporate a whole range of multimedia tools. The motivation of the present article was to draw some conclusions about the present state of research into multimedia learning based on the evidence provided in this handbook.

Mayer (2014b) defines multimedia learning as learning that occurs from words and pictures. Words usually take the form of some kind of explanatory text either narrated or written, and pictures can be either dynamic (e.g. animations and videos) or static (e.g. photos and graphs). Mayer's own research has established a well-known effect called the *multimedia principle* where deeper learning occurs from words and pictures compared with pictures alone (Mayer, 2014b). In more colloquial terms, two modalities are better than one. Significant research supports this principle as described by Butcher (2014). However, as will be noted later, there are some circumstances where the effect disappears or reverses. By definition, multimedia learning includes at least two modalities. Depending upon the different modalities used and the form they take, the cognitive processes activated can vary and lead to different learning outcomes. An integral theoretical consideration in multimedia learning is how learners build mental models from words and pictures. Mayer devotes four chapters in the handbook to what he considers to be fundamental theories or models that underpin existing research. They are briefly described next.

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## THEORIES/MODELS UNDERPINNING THE HANDBOOK

Mayer's *cognitive theory of multimedia learning* is based on three principles (Mayer, 2014c). Firstly, the information processing system has two channels for individual processing of visual/pictorial information. Secondly, each channel has limited processing capacity, and thirdly, active learning requires coordination of the cognitive processes (selecting and organising relevant words and pictures into coherent representations and integrating them with prior knowledge). When receiving multimedia materials, Mayer argues that extraneous processing must be reduced, essential processing must be managed and generative processing must be facilitated. An example of generative processing is learners creating their own drawings instead of having them supplied by the instructor (Leutner & Schmeck, 2014).

*Cognitive load theory* is a more general theory of instructional design and is based on research into human cognitive architecture (Paas & Sweller, 2014). Cognitive load is defined as the total load placed on working memory by instructional information. Three types of load are identified: intrinsic cognitive load is caused by the complexity of the materials to be learned, extraneous load is caused by the processing of unnecessary information, and germane load is caused by processing that leads directly to learning. A basic assumption of cognitive load theory is that too much cognitive load inhibits learning because of the limited capacity of working memory. Many of the effects identified by cognitive load theory involve multimedia learning (Sweller, Ayres, & Kalyuga, 2011).

Schnotz (2014) describes an *integrated model of text and picture comprehension*, where all three working memory components (sensory, working and long term) play a significant role. The model predicts a number of scenarios where text and pictures not only enhance learning but also reduce learning. It is argued that students learn better from words and pictures provided that they are semantically related to each other. But unlike Mayer's cognitive theory of multimedia learning, Schnotz argues that text and pictures have different functions in the comprehension process. Text guides conceptual processing of the information, whilst pictures can be considered visual tools that represent the subject matter. Both reading skills and prior knowledge play an important role.

The *four-component instruction design model* consists of four interrelated components that must be included for complex learning to successfully occur (van Merriënboer & Kester, 2014). The first component emphasises that learning tasks must be meaningful and real life. The second component argues that supportive information (scaffolding) must be provided to form a bridge between what the learner knows and what needs to be learned. The third component enables learners to perform the required procedures. The fourth component is a part-task practice that enables learners to automate the required routine skills. Van Merriënboer and Kester argue that for multimedia learning environments to be effective, opportunities should be provided for all these four components to be involved.

## FUNDAMENTAL ASSUMPTIONS UNDERPINNING THE FOUR HANDBOOK THEORIES/MODELS

The four theories or models described by Mayer have many similarities stemming from well-established memory research. Each use the three-component model of sensory memory, working memory and long-term memory, based on the work of Atkinson and Shiffrin (1968). Whilst sensory memory is considered important for receiving multimedia information through the sensory stores, as is the role of attention and perception, working memory receives the greater emphasis. It is assumed that learning requires conscious processing of information in working memory, which has very limited capacity (Cowan, 2001; Miller, 1956).

Both cognitive load theory (Paas & Sweller, 2014) and the cognitive theory of multimedia learning (Mayer, 2014c) argue that poorly constructed materials that increase working memory load will lead to ineffective learning. However, the main benefit of multimedia materials is that both use working memory, as originally proposed by Baddeley and Hitch (1974). It is generally argued that multimedia materials that use visual information (stored in the visuospatial sketch pad) and textual information (stored in the phonological loop) enable both subsystems to be used at the same time, which has an advantage over using only one subsystem. There are strong links with dual-coding theory (Paivio, 1986) in that the involvement of two modalities lead to the development of stronger mental representations. Interactions between working and long-term memory are also emphasised. It is generally argued that prior knowledge stored in long-term memory has to be integrated with the new information held in working memory to build new knowledge. Prior knowledge is also deemed essential to support the limited capacity of working memory through chunking strategies, as shown in expertise research (Ericsson & Kintsch, 1995).

## SOME BASIC IMPEDIMENTS TO LEARNING FROM MULTIMEDIA MATERIALS

The multimedia principle is now well established (Butcher, 2014; Mayer, 2014b). However, Ainsworth (2014) cautions that although deeper learning can occur when information is abstracted over multiple representations, it is not guaranteed. The handbook identifies a number of conditions when multimedia learning is detrimental to learning.

One such condition occurs when learners are forced to split their attention between two or more sources of information that are both essential for learning (Ayres & Sweller, 2014). For example, if one source (e.g. explanatory written text) is positioned away from a second source (e.g. diagram) either spatially or temporally, the learner has to waste working memory capacity (WMC) searching across the two sources and trying to match relevant components together. In cognitive load theory terms, this creates extraneous cognitive load, and learning is diminished (Paas & Sweller, 2014). One solution to this problem is to integrate the text and diagrams together, which decreases the number of searches that need to be conducted.

Another cause of difficulty is to include lengthy spoken text, which can be inferior to using written text (the reverse modality effect). According to Low and Sweller (2014), learners struggle to process lengthy spoken text because it is transient in nature. More working memory resources are required to store previously spoken information and integrate it with new information. In contrast, written text is more permanent and can be revisited, thus requiring fewer working memory resources than spoken text, to learn from.

Instructional animations also suffer from transient effects, as they are dynamic and fleeting in nature (Hegarty, 2014; Lowe & Schnotz, 2014). Just as narrated text disappears as soon as it is spoken, sequences of animated frames disappear as soon as they are observed (Ayres & Paas, 2007). Instructional animations can also contain information that is underwhelming or overwhelming (Lowe & Schnotz, 2014). More generally, multimedia environments can also include irrelevant materials and other gimmicky forms of ineffective enhancements that make it hard for the learner to sift through the relevant information in the correct order. In such cases, signalling and cuing strategies can be effective, helping to guide the learner towards appropriate information at just the right time (van Gog, 2014; Mayer & Fiorella, 2014).

Although there are many occasions when two modalities are better than one (the multiple media principle), this is not the case when two sources of information contain the same information. In such scenarios, the replicated information is redundant (Kalyuga & Sweller, 2014) and should be avoided (Mayer & Pilegard, 2014). According to Kalyuga and Sweller, redundant information, for example, a diagram containing the same information as the text, leads to a loss of learning, because unnecessary working memory processing takes place trying to integrate the two sources. Closely associated with redundancy is the expertise reversal effect, which has much wider implications (Kalyuga, Ayres, Chandler, & Sweller, 2003). This effect occurs when a strategy that is effective for novices becomes ineffective or impairs learning for more knowledgeable learners. There is considerable evidence in support of this effect including studies on multimedia learning. For learners with high levels of expertise, providing diagrams alone can be superior to diagrams and text (Kalyuga, 2014).

Prior knowledge also interacts with learner control. Whereas it is often argued that learner control aids learning because it generates active and constructive processing of information, the evidence in support of an advantage of learner control over system control is weak and likely to benefit only high-ability students (Scheiter, 2014). Similarly, using multiple documents online has special challenges because of truncated texts and having to navigate through the materials including hyperlinks (Rouet & Britt, 2014). Cues and directions, as well as making source information more salient, are necessary for low-ability learners to make such navigations.

Wiley, Sanchez, and Jaeger (2014) report that WMC can predict learning from illustrated text. They argue that greater WMC allows a reader to select and focus on specific information, as well as integrate and develop overall understanding. It enables more attention control and a focus on relevant stimuli. Like low prior knowledge, a lack of WMC means that learners will be more likely to suffer extraneous cognitive load when using multimedia materials. For learners with low WMC, more support such as explicit instruction is required.

## THE LACK OF RESEARCH INTO INTERACTIONS BETWEEN MULTIMEDIA ENVIRONMENTS AND THE EFFECTIVENESS OF GENERAL LEARNING STRATEGIES

In addition to how multimedia materials can be best designed, the handbook also describes investigations into some major instructional strategies embedded in multimedia learning environments. One such strategy is worked examples, which have been shown generally to be a highly effective strategy for novices and are a form of direct instruction. Renkl (2014) outlines the research on worked examples using multimedia materials, demonstrating that worked examples compared with other strategies, such as unguided problem solving, are effective in complex multimedia domains. Renkl also describes how worked examples can be enhanced by self-explanations.

Chi and colleagues have shown over a number of studies that self-explanations lead to deeper learning, by requiring learners to make inferences using the learning materials. Wylie and Chi (2014) describe how this successful strategy has been used with multimedia materials. Consistent with the general research into self-explanations, the role of prompts is emphasised, concluding that for multimedia materials, open-ended self-explanation prompts are less successful than those providing more direction.

From a cognitive load theory (Paas & Sweller, 2014) and a cognitive theory of multimedia learning perspective (Mayer, 2014b), discovery learning has been considered a poor alternative to direct instruction (Kirschner, Sweller, & Clark, 2006; Mayer, 2004). In their chapter, de Jong and Lazonder (2014) argue that material generated is better learned than that received directly from the instructor, citing research showing the effectiveness of guided rather than unguided instruction. De Jong and Lazonder stress the importance of enquiry learning in science, indicating that many multimedia environments such as computer simulations are particularly suitable for supporting this essential science skill. The authors stress the need for future research in multimedia environments that will facilitate collaborative discovery learning, consistent with science in the real world.

Collaboration is a theme discussed by Kirschner, Kirschner, and Janssen (2014), who provide a novel perspective by using the analogy of a grouped information processing system. They argue that a significant advantage of collaborative learning is that working memory load can be shared amongst the group members, thus reducing cognitive load (Kirschner, Paas, & Kirschner, 2009). However, tasks must be sufficiently demanding to warrant the sharing of information, because of communication transaction costs. It is argued that communication and coordination are vital for effective collaboration, and therefore, multimedia materials should be designed to offer such opportunities.

Johnson and Priest (2014) report that feedback has been found to be a significant factor in facilitating learning especially for novices. In multimedia environments, explanatory feedback (informing the learner why an answer is correct or incorrect) has often been compared with corrective feedback (indicating correct or incorrect only), where the former is superior. Much of this research has been in complex learning environments, such as games, simulations and interactive tutoring systems, where detailed and elaborated feedback is required. Like many of the chapters in the handbook, Johnson and Priest indicate the importance of identifying the appropriate boundary conditions. For example, there can be a negative impact if active cognitive processing is not stimulated, and many forms of feedback are not helpful for high prior-knowledge learners. It is also suggested that more research is required using different modalities and adaptive training systems.

It can be concluded that multimedia materials are suitable for conducting research into more general strategies for learning and, potentially, they might enhance them. However, it is also clear that the research reported has not varied the multimedia conditions to see what creates the optimum learning environment. The research indicates that, for example, worked examples are superior to unguided problem solving and feedback superior to no feedback, but it is not clear if certain types of multimedia add more value than others. More research is required into potential interactions between multimedia learning materials and general learning strategies.

## MORE RESEARCH IS REQUIRED INTO COMPLEX MULTIMEDIA LEARNING DOMAINS

The handbook includes a number of chapters focusing on complex multimedia learning domains. As Lajoie (2014) observes, computer-based technology has certain advantages in being able to generate interactions, provide sources of scaffolding in inquiry-based materials, use real-world problems in virtual worlds and provide a platform for immersive educational games. Examples include the use of interactive videos showing expert teaching practices enabling teachers to view and analyse behaviours supported by annotated text and hyperlinks (Derry, Sherin, & Sherin, 2014). Education programmes can be put online (e-courses), which can include a whole smorgasbord of multimedia designs, potentially interacting with student learning (Clark, 2014). Clark (2014) observes that e-courses may offer unique opportunities for individualised instruction and guided discovery;

however, more research is needed to validate if such technology can create effective learning environments.

It is clear that complexity creates a number of potential difficulties. Azevedo (2014) reports that many multimedia interactive environments involve nonlinear systems and open-ended learning and therefore require learner self-regulation to select, organise and integrate the content. Examples from Azevedo's research suggest that students find it difficult to self-regulate during such environments (e.g. hypermedia) and need adaptive scaffolding. A case is made that multimedia can be a two-way street in that self-regulation is required to learn effectively from them, but equally, multimedia materials can be used to develop metacognitive strategies. Azevedo concludes that little research has been conducted into multimedia learning and metacognition.

Nye, Graesser, and Hu (2014) report on studies that have shown that intelligent tutoring systems lead to learning gains. However, the interactivity has been found to be more important than the multimedia materials *per se*. It is argued that few studies have varied the multimedia factors, and because intelligent tutoring systems usually involve many multimedia tools, it is difficult to identify the most critical features. Nye et al. conclude that there is a need for greater alignment between multimedia features and intelligent tutoring system components.

According to Plass and Schwartz (2014), the complexity of simulations and microworlds is such that many forms of multimedia are included, mostly at the designer's discretion. Both simulations and microworlds have potential for inquiry learning and promoting social processes. Whereas the research has shown that simulations can be more effective than nonsimulations, less evidence exists showing that microworlds lead to learning gains.

Tobias, Fletcher, Bediou, Wind, and Chen (2014) argue that the central issue of learning from computer games is to achieve transfer of the cognitive processes from games to external tasks. The research suggests that considerable overlap is needed. Fast action games have been found to improve perception, attention and cognition, which have many potential learning advantages. Some studies (Mayer, 2011) have investigated multimedia factors such as spoken words, feedback and slide shows in game environments, emphasising the importance of multimedia design features, but the research is far from exhaustive.

The findings from these review chapters on complex multimedia designs suggest that much more research is required to unravel the intricacies involved. Certainly, some studies have shown that significant learning gains have been achieved using such complex systems, but the research should be considered to be at an early stage. Again, similar to the point made earlier, there seems to be a lack of research into interactions between the main featured strategy (e.g. games or simulations) and the actual multimedia materials used. Many questions remain unanswered: could games be more effective when using specific types of multimedia materials? However, it is worth emphasising that the more complex the learning environment, the greater the number of moderating factors that will be present, making the research very challenging.

## THE NEED FOR MORE COMPREHENSIVE THEORIES INVOLVING MULTIMEDIA LEARNING

Many authors report that more comprehensive theories are required to support the full range of multimedia learning research. For example, Lowe and Schnotz (2014) argue that it is vital to have theoretical models of how animations are processed, rather than a focus on comparisons between animations and statics. Scheiter (2014) concludes that there is a lack of theory linking learner control with self-regulated learning, particularly in hypermedia environments where learner control is required to choose which hypertext link should be selected. Azevedo (2014) discusses a similar theme arguing that broader theoretical models are needed to integrate cognitive, metacognitive, motivational and affective processes, in order for the field to progress. Plass and Schwartz (2014) also conclude that current theories of multimedia need to be extended to include affective factors.

Interestingly, although many of the chapters of this handbook include complex learning environments, little reference is made to existing models for complex learning such as the four-component instruction design model of van Merriënboer and Kester (2014).

## LIMITATIONS OF EXISTING RESEARCH

Several authors detail a number of limitations of their research topic. For example, a common theme is that much of the research has been conducted in laboratories rather that real learning environments (Butcher, 2014; Mayer & Fiorella, 2014). Another concern is that in many studies, the instructional presentations are very short with limited content (Mayer & Pilegard, 2014). Hence, much of the research has not been completed in real-life settings. A view is often expressed that more needs to be carried out to identify the boundary conditions for which a particular design or strategy is most effective (Renkl, 2014).

From a more holistic viewpoint, a number of other limitations can be identified. As previously discussed, there is a lack of studies that test interactions between different multimedia designs and supporting learning strategies such as self-explanations, or interactions between different multimedia designs and complex environments such as games. Either multimedia conditions or learning strategies are varied, but not both. Furthermore, research using multimedia materials to investigate specific learning strategies tends to compare the strategy (e.g. self-explanations) with an absence of the strategy (e.g. no self-explanations) rather than other comparable alternatives that generate similar types of cognitive engagement (Wylie & Chi, 2014).

There appears to be a lack of research into non-STEM (Science, Technology, Engineering and Mathematics) topics, with perhaps the only exception being research into teaching English as a second language (Kalyuga & Sweller, 2014). Is this just a lack of research focus, or are multimedia environments best suited to just STEM subjects?

Although prior knowledge and WMC are described as influencing the effectiveness of multimedia materials, the impact of spatial ability is not given the same status in the handbook. Research has shown that spatial ability impacts on learning with both dynamic and static visualisations (Höffler, 2010), and this moderating factor seems to be neglected. There is some evidence reported elsewhere that gender is also a factor in learning from animations (Sánchez & Wiley, 2010), specifically that females benefit more than males. If this is the case, then much more research is required to investigate this phenomenon, as well as factoring it into research designs when conducting more general research into animations (Wong, Castro-Alonso, Ayres, & Paas, in press).

Mayer (2014d) reports that social cueing is important in that using a human voice rather than a machine voice is more effective. Similarly, he argues that onscreen agents should show human behaviours and gestures rather than artificial movements. Recent research into gestures generally (Cook, Yip, & Goldin-Meadow, 2012) and multimedia instruction specifically (de Koning & Tabbers, 2011) suggests that embodied cognition approaches can be advantageous to learning and therefore could be included more frequently in multimedia research.

Whereas a great emphasis has been placed on dealing with extraneous processing (Paas & Sweller, 2012), little attention has been given to dealing with task complexity (intrinsic cognitive load). Some materials are hard to learn, regardless of the generative strategies used or the sophistication of the multimedia materials employed. Hence, specific strategies are required to deal with task complexity. Only Mayer and Pilegard (2014) seem to address this issue reporting on a pretraining strategy, suggesting that more wide-scale research is required to help learners deal with complex tasks.

Finally, Clark and Feldon (2014) identify 10 questionable claims that are made about the overall superiority of multimedia learning compared with other forms. These claims include that multimedia has the added advantages of motivation, animated pedagogical agents, learning styles, constructivist approaches, autonomy and control, critical thinking, incidental learning, interactivity and authentic learning. Clark and Feldon review each claim and dismiss them through lack of supporting evidence. The other authors in the handbook discuss many of these topics but do not make such firm claims about the superiority of multimedia learning. They certainly advocate that multimedia materials are particularly apt for the inclusion of such additions but do not argue for overall superiority, which is supported by the findings of Clark and Feldon (2014).

## CONCLUSIONS

The handbook is well researched, focusing on empirical evidence, and Mayer is to be congratulated on editing it, as well as the authors who have all made significant contributions. A number of conclusions can be drawn from these review chapters. Firstly, the research into the multimedia effect (two modalities are better than one) is thorough and quite conclusive. There are a number of well-established theories and models that can explain how multimedia benefits learners, which are underpinned by earlier classical research into human memory (e.g. Baddeley & Hitch, 1974; Miller, 1956) and dual coding (Paivio, 1986). The research suggests that the boundary conditions of basic multimedia learning are well known. Two or more modalities can become ineffective if the instructional designs include split-attention, redundant or transient materials or used learners with high levels of prior knowledge.

For more complex multimedia learning environments, the research is much less conclusive and should be considered as in its infancy. Using multimedia materials, a number of general strategies (such as worked examples and feedback) have been shown to be effective, compared with other strategies, such as problem solving and no feedback. However, there is a lack of research investigating which multimedia designs best complement specific learning strategies. There is also a lack of research investigating interactions between multimedia designs and more complex learning environments such as games and computer-based tutors. Again, studies have shown that learning can be achieved with strategies that require complex designs, but little research has been conducted into varying the multimedia conditions. There also appears to be a need for more comprehensive theories that include the affective domain, such as self-regulation.

In summary, even though this handbook may not represent all the research conducted into multimedia learning, it can be concluded that when multimedia materials are fairly straightforward, we know a lot, but when they are more complex, we know far less. In highly complex domains, there are far more interacting factors that, if not carefully considered, may create booby traps for the learner. We know how to avoid many of these pitfalls, by following many of the principles (design and supportive) outlined in the handbook, but much more is required to fully understand the world of complex multimedia learning. The handbook underlines what many researchers have concluded in the past: we have great knowledge of how to design sophisticated multimedia materials but far less about how today's technology can create really effective learning environments.

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