8 The Split-Attention Principle in Multimedia Learning

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Abstract

The split-attention principle states that in the design of instruction, including multimedia instruction, it is important to avoid materials that require learners to split their attention between, and mentally integrate, multiple sources of information. Instead, materials should be formatted so that disparate sources of information are physically and temporally integrated, thus obviating the need for learners to engage in mental integration. Eliminating the need to mentally integrate multiple sources of information reduces extraneous cognitive load and frees resources for learning. This chapter provides the theoretical rationale, based on cognitive load theory, for the split-attention principle, describes the major experiments that establish the validity of the principle, identifies the conditions under which it is most likely to occur, and indicates the implications for instructional design involving multimedia materials.

Definition of Split Attention

Instructional split attention occurs when learners are required to split their attention between and mentally integrate several sources of physically or temporally disparate information, where each source of information is essential for understanding the material. Cognitive load is increased by the need to mentally integrate the multiple sources of information. This increase in extraneous cognitive load (see Chapters 2 and 3) is likely to have a negative impact on learning compared with conditions where the information has been restructured to eliminate the need to split attention. Restructuring occurs by physically or temporally integrating disparate sources of information to eliminate the need for mental integration. The split-attention effect occurs when learners studying integrated information outperform learners studying the same information presented in split-attention format. The split-attention principle flows from the split-attention effect and states that when there are disparate sources of information that must be mentally integrated in order for the information to be understood, those sources of information should be presented in an integrated format.

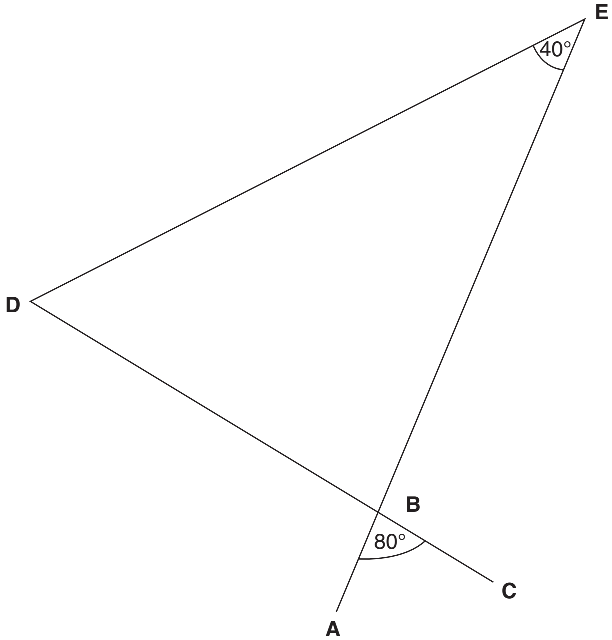
An Example of the Split-Attention Effect

The problem and solution shown in Figure 8.1 provide an example of the split-attention effect. In the figure, a solution to an elementary geometry problem is presented in a traditional split-source format, in which the solution is below the diagram. The diagram provides all the required information to solve the problem. Although there are several possible solution paths, the worked example provides a two-step solution. Because the solution is adjacent to rather than within the diagram, this example has a split-source format.

The given solution requires the learner to read each statement and examine the diagram to determine the correspondence between the information referred to in the statement and that contained in the diagram. This process of matching the solution statements with the diagram requires several searches of the diagram to be completed. In searching, information from both the diagram and the text needs to be retained in working memory. Furthermore, both sources of information need to be revisited several times before the information can be adequately aligned. The mental processes involved in searching and then integrating that information create an extraneous cognitive load caused by the design of the worked example. Fundamental to cognitive load theory is that extraneous cognitive load interferes with learning as scarce working memory resources are consumed by unnecessary processing (see Sweller, Ayres & Kalyuga, 2011; Sweller, van Merriënboer & Paas, 1998).

In contrast to the split-source format exemplified in Figure 8.1, the worked example shown in Figure 8.2 has an integrated format in which the solution statements are embedded directly into the diagram. This format reduces the need to search for referents and reduces working memory load, as less information has to be kept in temporary storage. Each solution statement is positioned directly where the sub-goal and goal angles under consideration are located. The two steps are also numbered to make it easy for the learner to follow the correct sequence. In this physically integrated format, the extraneous cognitive load is significantly reduced compared with that in the split-attention format. Consequently, more working memory resources can be concentrated on schema acquisition that is germane to learning rather than on unnecessary search and integration processes that are extraneous to learning. Under such conditions, physical integration provides a substitute for mental integration, which is kept to a minimum by the integrated format. Hence, the split-attention effect can be explained by differences in extraneous

Problem: Find the value of Angle BDE



Solution
∠DBE=80 (Vertically opposite angles)
∠BDE+40+80=180 (Angle sum of a triangle)
∠BDE+120=180
∠BDE=60

Figure 8.1. *Split-attention format.*

cognitive load. Split-attention materials generate more extraneous load than integrated materials, resulting in reduced learning.

In order to obtain the split-attention effect, the logic of the relations between multiple sources of information is critical and needs to be emphasized. The effect requires the multiple sources of information to be unintelligible in isolation. In the current example, the instructional module is meaningful only when both sources of information are considered together. Neither the diagram nor the textual solution can be understood or provide meaningful instruction in isolation. Without the diagram, the textual solution has no meaning, and similarly, without the text, the diagram alone does not provide a problem or an answer. Both are needed for the instruction to be intelligible. This relation between the diagram and the text is required to demonstrate the split-attention effect but is not universal. Textual information that merely redescribes a diagram, for example, is redundant and will not yield the split-attention effect. Rather, the different logical relation between multiple sources of information inherent in redundant information can lead to the redundancy effect that is discussed in Chapter 10.

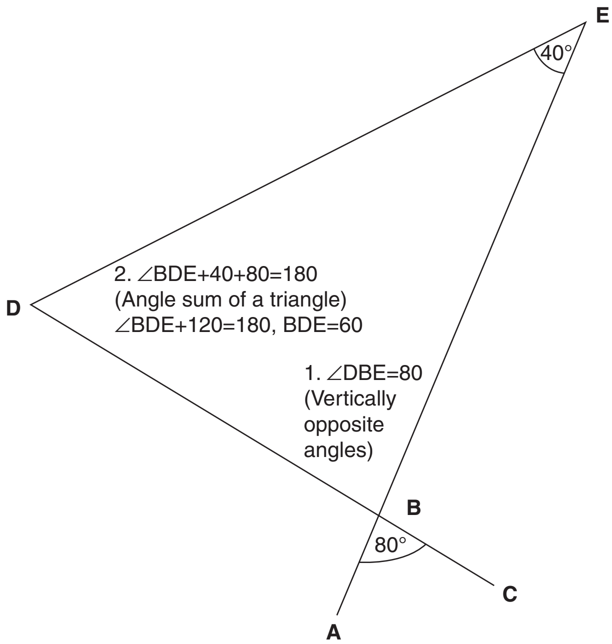


Figure 8.2. *Integrated format.*

Initial Research: Split-Attention Effect and Worked Examples

Tarmizi and Sweller (1988) conducted the initial research on the split-attention effect using worked examples in geometry. Prior to this study, worked examples had proved to be highly effective in comparison with conventional problem-solving strategies for learning mathematics (see Cooper & Sweller, 1987; Sweller & Cooper, 1985; Zhu & Simon, 1987). However, in their initial experiments, Tarmizi and Sweller found that worked examples did not enhance performance compared with conventional problem-solving strategies. To explain this failure, Tarmizi and Sweller reasoned that the traditional geometry format of worked examples, a diagram followed by solution steps (see Figure 8.1), must increase cognitive load due to split attention and that if diagrams and texts were integrated, then split attention would be avoided. In the final two experiments of this study, Tarmizi and Sweller successfully showed that the performance of learners who studied integrated worked examples was superior (i.e., fewer errors and quicker solution times) to that of learners who followed a conventional problem-solving strategy during acquisition.

Following the identification of the split-attention effect and the success of integrated material in the geometry domain, researchers sought to test these findings in other domains. Sweller, Chandler, Tierney and Cooper (1990) replicated the Tarmizi and Sweller findings using coordinate geometry materials. Again, traditionally structured worked examples in this domain have used a diagram associated with solution steps next to or under the diagram. Using this format, as indicated earlier, learners are forced to search for the location of referents in either the diagram or the text, and that search process requires working memory resources. Sweller et al. (1990) found that learners who studied worked examples formatted in the traditional way performed no better than learners who were required to solve a conventional problem. In contrast, learners who studied an integrated worked example format where steps to the solution were written on the diagram at locations designed to reduce unnecessary search performed significantly better than learners solving problems or studying conventionally structured worked examples. Furthermore, as might be expected, these results were not restricted to instruction using worked examples. In further experiments, Sweller et al. found that initial instructions presented in an integrated format were superior to the same instructions presented in a split-attention format.

Ward and Sweller (1990) found additional evidence of the split-attention effect in the area of physics. Using mechanics problems based on the formulas associated with constant acceleration, Ward and Sweller found that worked examples compared poorly with a problem-solving strategy because of split-attention caused by the separation of initial formula statements and substitution manipulation steps for known values. Once all steps were integrated physically, Ward and Sweller successfully showed that integrated worked examples were superior to both a problem-solving strategy and conventionally (split-attention) structured worked examples .

Split-Attention and Explanatory text

As previously described, the initial research on the split-attention effect was conducted with worked examples demonstrating procedural mathematical steps. However, many learning environments are constructed using explanatory text (spoken or written) combined with diagrams, rather than worked examples. Many of these designs are often presented in a split-attention format, as the text is not integrated fully with the diagrams. This section outlines the evidence for the split-attention effect using explanatory text.

Sweller, Chandler, Tierney and Cooper (1990) extended their research on coordinate geometry by studying the structure of explanatory text. Instead of writing explanatory notes below a diagram, they labelled the notes and embedded them into the diagram at the closest point of reference, thus reducing problem-solving search. In this study, Sweller et al. demonstrated the split-attention effect by showing that physically integrated explanatory notes were more effective than notes written below the diagram in a split-source format. Sweller et al. also extended their findings by including the learning domain of numerical control programming using two sources of text. In this experiment, one group of students was instructed using a single set of instructions created by integrating both sources of information, and this group was compared with a second group that received two separate sets of instructions presented successively. The results indicated that the integrated group required less time to study the information and obtained higher scores on subsequent tests.

During this early period of investigation into split attention by cognitive load theory researchers, the effect was also confirmed with learning materials involving geography (Purnell, Solman & Sweller, 1991) and electrical circuits (Chandler & Sweller, 1991).

As well as research generated by cognitive load theory, substantial work on the split-attention effect has been carried out by Richard E. Mayer. Although Mayer has focused more generally on how illustrations and animations facilitate learning, his research has also extended the knowledge base on split-attention and other cognitive load theory phenomena, particularly in the computer domain.

Early work by Mayer (1989) indicated that including illustrations in expository scientific text has clear advantages. In two experiments, Mayer demonstrated that the use of labelled illustrations during instruction was particularly effective. Mayer found that providing pictures without labels or labels without pictures was inferior to providing both together. Mayer concluded, 'without a coherent diagram that integrated the information, students performed relatively poorly on problem solving transfer' (p. 244). In this study, Mayer identified the importance of integrated information using the operation of hydraulic braking systems as a learning domain. While this work was not directly concerned with the split-attention effect, it is notable that both the labels and text were presented in a fashion that avoided split attention.

Although Mayer (1989) did not compare integrated with nonintegrated information directly, a later study did. In developing a generative theory of textbook design, Mayer, Steinhoff, Bower and Mars (1995) argued that an important step for meaningful learning to occur was to build connections between pictorial and verbal representations. Furthermore, they argued that this was more likely to occur when text and illustrations were presented 'contiguously' (p. 33) on the page rather than separately. To test this hypothesis, a series of experiments was designed around instruction on how lightning worked. In this study, undergraduates with various levels of knowledge about lightning were randomly assigned to either an integrated-format group or a separated-format group. Students in the integrated group received a 600-word text on one page and five illustrations about how lightning worked on a facing page in the same booklet. Each illustration, which also contained labels and a caption, was placed next to the corresponding paragraph that described it. In contrast, the separated group received the same 600-word text and illustrations (without labels and captions) in separate booklets. The results of this study showed that students who received the integrated materials performed at a higher level on subsequent problem-solving tasks than students who received separated materials. However, this difference was observed only with students who had a low knowledge base prior to commencing the trial. For students with a greater understanding of meteorology, no difference was found between the two groups.

Further evidence of the beneficial effects of presenting verbal and visual materials in an integrated format came from Moreno and Mayer (1999). In a computer-based environment using meteorological tasks, Mayer and Moreno showed that the text and diagram did not have to be on different pages or substantially removed from each other to produce a split-attention effect. Differences could be quite subtle. In this study the on-screen text was placed at the bottom of the screen beneath the corresponding diagram, while the integrated-format group's text was placed near the relevant section of the diagram. On tests of verbal recall and transfer, the integrated-format group outperformed the separated-format group. Even though the text was short and the diagrams were straightforward, the separated group was forced to expend more cognitive resources than the integrated group to assimilate the information. A further finding of this study was that students who received illustrations with no written text at all, but with a concurrent narration, performed at a higher level than the other two groups, providing an example of the modality effect (see Chapter 9).

Over a number of studies, Mayer and his colleagues collected evidence that integrating words and pictures leads to superior learning compared with a more spatially remote multimedia design. These findings led Mayer (2001) to formulate the *spatial contiguity principle*: 'Students learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen' (p. 81). This statement exemplifies the split-attention effect. Later studies extended research on split attention and explanatory text to other learning domains, including accountancy (Rose & Wolfe, 2000), music (Owens & Sweller, 2008), complex orthopaedic physical therapy skills, taught in a realistic classroom setting (Pociask & Morrison, 2008), and the structure and physiological processes involved in the human kidneys (Cierniak, Scheiter & Gerjets, 2009).

e-Learning and the Split-Attention Effect

The research on the split-attention effect has identified many learning environments where integrated rather than split-source information should be used. Potentially, any instructional material that contains more than one source of information is a candidate for integrating split-source information. However, the initial research focused on materials that were presented solely using paper-based media. When researchers turned their attention to learning in a computer environment (e-learning) the research base was significantly expanded.

In the initial days of computers, learning how to use computer and/or computer applications relied heavily on an accompanying computer manual. Such manuals are still common, although screen-based information is now more prevalent. Typically, computer manuals contain instructions that the reader must follow while attending to information on the computer screen and using a keyboard and mouse. In these situations, split attention between the manual, computer and keyboard seems inevitable.

Sweller and Chandler (1994) and Chandler and Sweller (1996) were the first to demonstrate the split-attention effect caused by the simultaneous use of both manual and computer-based information. Sweller and Chandler (1994) tested a conventional method of learning a computer application against an integrated approach designed to reduce split attention. For the conventional method, students were required to learn a CAD/CAM (computer-aided design / computer-aided manufacture) package using both a manual and a computer. This conventional procedure required a number of mental integrations between the instructions in the manual, use of the keyboard and displays on the computer screen. To reduce split attention, those in the integrated group received all their instructions in a modified manual. No computers or keyboards were used. Instead screens and keyboards were replaced by diagrams in a manual. Furthermore, to reduce split attention within this medium, text and diagrams were fully integrated, requiring students to follow a number of ordered steps. In a direct comparison based on a post-acquisition test that included use of the hardware, the group following the integrated approach using no hardware was found to be superior to the conventional group, suggesting that the simultaneous use of a manual and computer created a split-attention effect. That effect resulted in students who had had practice using the hardware demonstrating less proficiency in hardware use than students who had learned without direct access to the relevant equipment.

In a second study, Chandler and Sweller (1996) reproduced this result, again demonstrating that the presentation of fully integrated instructions of a computer application on paper alone was superior to the simultaneous use of a computer and a manual. Practice using the computer was far less important than properly formatted instructions presented on paper. Over the two studies, Chandler and Sweller demonstrated the effect using a number of different materials. However, these studies also identified the critical importance played by element interactivity. Element interactivity refers to the number of elements that must be simultaneously processed in working memory in order for the learner to understand the information. Materials low in element interactivity are easy to learn because they keep working memory demands to a minimum. In contrast, materials high in element interactivity are more complex and place more demanding loads on working memory. Element interactivity affects intrinsic cognitive load, whereas split attention causes extraneous cognitive load because it is created by the format of the instructional materials (Sweller et al., 1998; see also Chapter 2).

In their two studies, Chandler and Sweller found that the split-attention effect occurred only when the materials were high in element interactivity. Clearly, in these computer environments, the interaction between intrinsic and extraneous cognitive load was extremely important. For very simple tasks, such as adding data to a spreadsheet cell using the computer and manual simultaneously, split attention may have little effect because of low element interactivity. An inadequate instructional format may not overload working memory if the intrinsic cognitive load associated with the task is low. For tasks high in element interactivity, such as completing a complicated spreadsheet formula, a split-attention format will have a negative impact on learning. A heavy working memory load due to high element interactivity and split attention may be overwhelming.

The Chandler and Sweller results described so far may appear to be controversial or counterintuitive, as they seem to suggest that the best way to learn about computers is not to use one. However, as these authors argued, the integrated noncomputer approach was best suited to acquiring computer skills at the very early stages of learning. Obviously, we need to use computers at some stage and, indeed, Chandler and Sweller (1996) made the following point about the strategy: 'It can be suggested that, under some circumstances, the removal of computing equipment during critical phases of learning may provide considerable benefit' (p. 168).

Following the success of the integrated-manual approach, Cerpa, Chandler and Sweller (1996) reasoned that its effectiveness could plausibly be due to differences in the media rather than split attention; that is, paper-based material may enhance learning compared with electronic versions. Consequently, Cerpa et al. devised a study to test this possibility. Instead of integrating the materials on paper, they constructed a fully integrated package for viewing on the computer. Working in the domain of spreadsheet learning, students were asked to acquire a number of skills, ranging from selecting cells, rows and columns to using functions and entering formulas. An integrated design was constructed by inserting all the instructions into the software at the appropriate points, thus reducing the effects of split attention. One group of students received instructions in this integrated mode and was compared with a second group that received a traditional instructional package of manual and computer.

On test questions following the instructions, the integrated group (computer-only) significantly outperformed the split-attention group (computer plus manual). However, this difference was found only on test questions tapping knowledge that was high in element interactivity, such as creating a formula. On tasks of low element interactivity such as selecting a row, no differences were found between groups. The results of this study eliminated the possibility that print media were superior to an electronic medium and provided further support for the split-attention effect and the influence of element interactivity. The study also demonstrated that computers could be used effectively provided that the split-attention effect was avoided.

Temporal Versions of the Split-Attention Principle

The split-attention examples described so far all have one thing in common: the various sources are physically separate. Regardless of whether the cause of split attention is text and a diagram, or computers and a manual, the two different sources of information are physically separate in a manner that requires search in order to locate relevant referents. It is that act of search for referents that imposes an extraneous cognitive load.

Physical separation is not the only form of separation generating unnecessary search. Multiple sources of information that must be integrated before they can be understood also can be separated in time, resulting in temporal separation. It is reasonable to suppose that temporal separation also generates an extraneous cognitive load for exactly the same reasons as physical separation. Learners must unnecessarily find referents between separated sources of information, in this case temporal separation, and that requirement to mentally coordinate multiple sources of information requires working memory resources. Temporal integration – that is, the simultaneous presentation of multiple sources of information that must otherwise be mentally integrated before they can be understood – should reduce the need for mental integration and so reduce extraneous cognitive load. A comparison of temporally separate and integrated instruction should yield evidence of superior learning under integrated conditions, yielding a temporal version of the split-attention effect. As already indicated, Mayer and his colleagues have researched the phenomena associated with presenting diagrams and text together during instruction, but in addition they have considered the consequences of temporal rather than spatial versions of the split-attention effect.

Mayer (2001) called this principle the *temporal contiguity principle:* 'Students learn better when corresponding words and pictures are presented simultaneously rather than successively' (p. 96). So far, all instructional materials reported in this chapter have engaged the learner in the visual medium only. However, the temporal contiguity principle extends the split-attention theory to spoken text. Since the invention of the modern cinema, pictures and the spoken word have been presented together to provide instruction on a film screen, a television screen and, more recently, a computer screen (although we must not forget that teachers have been reading to their students while simultaneously presenting pictures or demonstrating skills for considerably longer). Consequently, how spoken words and pictures should be presented is also an important consideration.

Mayer (2001) argued that because of the limitations of working memory, words and pictures should not be separated temporally. For example, consider the case of a computer-based multimedia presentation in which a narration episode is followed by an animation episode that depicts the content of the narration. To understand fully what both episodes mean, the learner must hold some or all of the narration in working memory and then integrate this narration with the animation. This mental integration may require considerable working memory resources to achieve, diverting them from learning.

Mayer developed the temporal contiguity principle on the basis of the results of a number of studies conducted using animation in a computer-based environment. An initial influence was a study by Baggett (1984). Baggett designed an experiment in which a film was shown to college students in which the visual and auditory components (voiceover) were presented under seven different conditions. Three conditions presented the visual material either 7, 14, or 21 seconds before the auditory component, and three conditions presented the visual material either 7, 14, or 21 seconds after the auditory components. The final condition presented both the visual and auditory materials simultaneously. On recall tests, students who received the concurrent mode or the visuals 7 seconds before the voiceover performed at a superior level to the other five groups. This experiment demonstrated the importance of presenting both media together in close proximity.

Initial research by Mayer and Anderson (1991) compared the effect of receiving instruction that presented words before pictures with the effect of receiving instruction that presented both words and pictures simultaneously. In the first experiment of this study, students studied an animation that showed how a bicycle tire pump worked. A words-before-pictures group received a narrative description of how the pump worked before the animation (silent) was presented. A words-with-pictures group received both sound and pictures simultaneously. The group that received the simultaneous presentation scored higher on subsequent problem-solving tasks.

In a second study, Mayer and Anderson (1992) extended this research. The number of presentations was increased, and the impact of varying the order of narration and animation was examined. On problem-solving tasks, a concurrent group outperformed all other groups and, notably, groups that received narration before animation, or vice versa, performed at the same level as a control group with no instruction.

Mayer and Sims (1994) also found evidence that a concurrent presentation of narration and animation was superior to a sequential presentation of either narration followed by animation or animation followed by narration on problem-solving tasks. The study domains were the human respiratory system and bicycle pumps. In addition, this study also examined the influence of spatial ability on these presentation modes. For learners with high spatial ability, there was a significant temporal contiguity effect. However, for learners with low spatial ability, the concurrent group performed at the same level as the sequential group. Mayer and Sims explained this finding by arguing that students with low spatial ability had to devote relatively more cognitive resources to connecting the two sources of information than did students with high spatial ability. In particular, high spatial awareness was particularly advantageous in building visual representations.

These studies demonstrated that students who received information simultaneously (integrated narration and animation) outperformed students who received nonintegrated instructions (narration and animation separated temporally). These differences were found consistently on transfer (problem-solving) tests and less frequently on retention tests. The results support Mayer's temporal contiguity principle (Mayer, 2001).

In further research on temporal contiguity, Moreno and Mayer (1999) investigated the impact of using smaller segments in computer-based episodes of narration and animation. In this study, the large instructional episodes on the formation of lightning used in previously described experiments were divided into 16 smaller segments. Groups of students were presented with either 16 successive alternations of mini-narrations and animation in that order, or vice versa. These groups were compared with students who received the whole episode in an integrated fashion described previously. As few differences were found between groups on retention and transfer tests (results marginally favoured the integrated whole-episode approach), Moreno and Mayer (see also Mayer, 2001) concluded that students who received the smaller-segment episodes were not subjected to high working memory loads because successive presentations were very short (one or two lines at a time). Consequently, learners were able to successfully integrate the two sources of information themselves and performed at a level comparable to the fully integrated approach.

The results supporting the temporal contiguity principle are also consistent with the transient information effect (Sweller et al., 2011). The transient information effect occurs when learning is reduced as a result of transient information disappearing before the learner has time to adequately process it. All spoken information is transient unless it is written down or repeated in some form. Evidence of its negative impact has been found in multimedia environments that feature spoken text (see Leahy & Sweller, 2011; Singh, Ayres & Marcus, 2012) or instructional animations (see Ayres & Paas, 2007; Wong, Leahy, Marcus & Sweller, 2012). Any substantial amount of spoken text or animation with high element interactivity can be difficult to store and process in working memory due to transience. If learners have to also process a diagram that is displaced temporally, then the extraneous cognitive load may be even higher.

Split-Attention Caused by More Than Two Sources of Information

Most of the research on the split-attention effect has featured two sources of information. More recent research has examined the effect of more than two sources. In a study that investigated learning Chinese as a second language, Chung (2007) used three different sources of information simultaneously: flash cards consisting of a Chinese character, the English translation and the pinyin (using English letters) equivalent. A split-attention effect was found, with superior learning obtained when the English or pinyin card was presented physically close to the Chinese character rather than spatially apart.

Lee and Kalyuga (2011) also investigated the effectiveness of pinyin in learning Chinese as a second language using the same three sources of information as Chung (2007). They found that the commonly used horizontal layout format for presenting pinyin, with the Chinese characters first, followed by the pinyin to the right, led to a high degree of split attention, as learners had to search and match corresponding characters and pinyin. Lee and Kalyuga reduced split attention by placing the pinyin directly under the corresponding Chinese characters in a vertical format. In an experiment with high school students, a significant learning advantage was found for the vertical over the horizontal format.

Additional Methods to Prevent Split Attention

The studies reported so far used a physical integration strategy to deal with split attention. A number of alternative strategies have also been researched.

Directing Attention

Instead of integrating the split-attention sources, Kalyuga, Chandler and Sweller (1999) reduced visual search by directing attention using a colour-coding system to connect the text directly to the relevant parts of the diagram. In learning about electrical circuits, students clicked on a section of text that immediately identified the relevant parts of the diagram to be considered by changing their colour. When compared with a split-source format, where the text was written below the diagram, directing visual gaze was found to be superior. Tabbers, Martens and van Merriënboer (2000) also found that colouring relevant parts of a diagram was effective in overcoming split-attention materials.

Florax and Ploetzner (2010) also investigated attention-direction strategies by combining segmentation and signalling techniques. When they divided explanatory text into smaller segments, which were labelled with a number corresponding to an equivalent number on the matching diagram, they found learning to be equally effective as learning with fully integrated materials (text segments inserted into the corresponding diagrams) and superior to learning with a split-attention format (unsegmented text displaced from the relevant diagram). The positive impact of segmentation on split attention supported previous findings by Mayer and colleagues (see Mayer et al., 1999; Moreno & Mayer, 1999).

Hypertext Strategies

A further strategy to reduce the effects of split attention is to use hyperlinks, which introduces an element of learner control. To avoid cluttering presentations with large sections of integrated text, Bétrancourt and Bisseret (1998) inserted text into diagrams that were visible only when the learner clicked on the mouse. This 'pop-up' procedure was found to be superior to a split-source format (all text to the right of the diagram) and equal to the more traditional integration method (all text embedded into the diagram). In a similar experiment, Erhel and Jamet (2006) found supporting evidence that a pop-up design was superior to split-source materials. In addition, on some measures (e.g., making inferences), the pop-up procedure was found to be more effective than an integrated format.

Helping the Learner Overcome Split Attention

In all the studies previously referenced, the researchers provided learners with an integrated condition. However, learners are frequently required to deal with materials that are presented in split-attention formats without the help of designer-integrated materials. Hence, a significant educational goal is to equip students with strategies to deal with such instructionally inappropriate learning environments (Ayres & Paas, 2012). Two notable studies have been completed in which the emphasis has been placed on the learner actively integrating the materials themselves.

In the first study, Bodemer, Ploetzner, Feuerlein and Spada (2004) required learners to physically integrate split-source materials in which written text was positioned above diagrams by moving the text into the diagram using interactive computer commands. Consequently, learners engaged in both physical and mental integration. Although not entirely conclusive, some evidence emerged that a combination of mental and physical integration was superior to mental integration alone. Such learner interactivity had a positive effect.

In the second study, by Roodenrys, Agostinho, Roodenrys and Chandler (2012), students were directly taught how to deal with split attention by using integration management techniques. These techniques required learners to draw circles around key sections of information in both sources of information and link them together with arrows, as well as to number each step in the sequence. In this study, the self-management group was compared with two other groups that received instruction either in split-attention or designer-integrated format. The results indicated that the self-management group performed at the same level as the designer-integrated group and that the performances of both were superior to that of the split-attention group. Furthermore, those in the self-management group were able to transfer their management strategies to new materials.

Conditions When the Split-Attention Principle May Not Occur

Although many studies have demonstrated the split-attention effect, some have noted certain conditions or specific learner categories where the effect failed to occur. For example, one series of studies completed by Chandler and Sweller (see Cerpa et al., 1996; Chandler & Sweller, 1996; Sweller & Chandler, 1994) found that the effect occurred only when information of high element interactivity was used. For materials low in element interactivity, where elements of information can be learned individually without complex integration, the split-attention effect did not occur. From this perspective, the split-attention effect is consistent with many other cognitive load theory effects in that element interactivity must be high for the effects to be observed (see Sweller et al., 2011).

Furthermore, as previously indicated, the logical relation between sources of information is critical for the split-attention effect. The effect can be obtained only when multiple sources of information are essential for understanding and so cannot be understood in isolation. If multiple sources of information provide the same information in different forms and so are redundant, integrating them is not beneficial. Chandler and Sweller (see Chandler & Sweller, 1991, 1996; Sweller & Chandler, 1994) obtained empirical evidence that an integrated format could be less effective than a diagram alone if the information on the diagram and that in the text relayed the same information. The diagram-only treatments were superior to the integrated format because redundant material was excluded (see Chapter 10 on the redundancy effect).

A further factor important for the split-attention effect, again consistent with many other cognitive load theory effects, is the influence of prior knowledge. Studies on learning English as a second language (see Yeung, Jin & Sweller, 1998) and learning about electrical circuits (see Kalyuga, Chandler & Sweller, 1998) showed that an integrated approach was unnecessary for more knowledgeable learners, because additional explanatory text, essential for novices, was found to be redundant for more expert learners. For more expert learners, the results were reversed, with a split-attention format superior to an integrated format, thus providing an example of the *expertise reversal effect* (Kalyuga, Ayres, Chandler & Sweller, 2003; see also Chapter 24).

Investigating Split Attention through Eye Tracking

Because of the influence of visual search when information is presented in split-attention format, eye tracking has emerged as a useful tool for investigating learners' search processes (Ayres & Paas, 2012). According to van Gog and Scheiter (2010), eye tracking provides insights into how learners process information, including perceptual processes that are not normally observable, and therefore it is particularly suited to research on multimedia effects. Bauhoff, Huff and Schwan (2012) provide an example of using eye tracking to gain insights into attention allocation when problem solvers are given split-attention materials. In this study, split-attention materials were presented in the form of two static pictures of a mechanical clock. The problem solvers were required to find differences between the two sources while the spatial distance between them was varied. The results indicated that as the distance between the two sources increased, gaze shifts decreased and dwell times increased. The authors argued that as gaze shifts decreased, working memory use increased, as larger chunks of information had to be memorized between gazes. The finding is interesting because it suggests that quite small differences in the spatial distance between sources of information can lead to changes in cognitive processes. This study provides a good example of how eye tracking might be advantageous in future research on the split-attention principle. Similar results were reported in an eye-tracking study by Johnson and Mayer (2012).

Implications for Instructional Design

The split-attention effect is a robust, easily demonstrated effect leading to the split-attention principle: where instruction includes multiple sources of information that must be mentally integrated in order to be intelligible, those sources of information should be both physically and temporally integrated in order to reduce unnecessary search for referents and so reduce extraneous cognitive load. There are now many studies demonstrating that substantial learning gains can be achieved by physically integrating disparate sources of information rather than requiring learners to use mental resources in mentally integrating the same information. Those studies use a wide variety of materials and participants under many conditions. According to a meta-analysis by Ginns (2006), more than 50 studies were completed by 2006, including both spatial and temporal investigations. The overall effect size was large (a Cohen's *d* value of 0.85). Since 2006, many more studies have been completed, further refining our knowledge of this important instructional effect.

Notwithstanding the strength of the split-attention effect, we must take considerable care when physically integrating disparate sources of information. For example, simply placing all text into a diagram is no substitute for an understanding of the split-attention principle. There are many conditions under which the principle does not apply or, worse, where attempts to apply the principle will have negative rather than positive effects on learning. We would like to emphasize the following points:

1. The principle applies only when multiple sources of information are unintelligible in isolation. For example, physically integrating a diagram with statements that merely redescribe the diagram and so are redundant has negative, not positive, effects on learning due to the redundancy effect (see Chapter 10). If all sources of information are intelligible in isolation and redundant, elimination of redundancy rather than physical integration should be pursued. Thus, analysing the logical relation between multiple sources of information prior to physical integration is critical.
2. The split-attention principle applies only to material high in element interactivity. If intrinsic cognitive load is not high, whether or not an extraneous cognitive load is added due to split attention is likely to be irrelevant. A diagram and related text that have few interacting elements and so are easily understood are unlikely to be rendered more intelligible if they are physically integrated. They can be easily learned even when presented in a split-source format.
3. Whether sources of information are intelligible in isolation, and whether the information is high in element interactivity, depends not only on the instructional material, but also on learner characteristics. Material that is unintelligible in isolation and high in element interactivity for low-knowledge learners may be intelligible in isolation and low in element interactivity for learners with more knowledge. For high-knowledge individuals, physical integration may be deleterious, resulting in the expertise reversal effect (see Chapter 24). Alternative instructional techniques are required under such circumstances, with the elimination of redundant information being the most common technique.

Conclusions

Split attention is pervasive. The format of much instruction is determined by tradition, economic factors or the whim of the instructor. Cognitive factors are rarely considered, resulting in instructional designs in which split attention is common. Cognitive load theory, which gave rise to the split-attention principle and which is based on an understanding of human cognitive architecture, especially the relations between working and long-term memory, provides theory-based and experimentally tested instructional guidelines. Those guidelines that are associated with the split-attention effect and that have been discussed in this chapter have the potential to substantially improve multimedia instruction.

Glossary

Integrated instructions: Instructions in which multiple sources of information are physically integrated so that working memory resources do not need to be used for mental integration. Can be contrasted with split-attention instructions.

Split-attention instructions: Instructions in which multiple sources of information are not physically or temporally integrated so that working memory resources need to be used for mental integration. Can be contrasted with integrated instructions.

Temporal contiguity principle: Students learn better when corresponding words and pictures are presented simultaneously rather than successively.

Transient information effect: Occurs when learning is reduced as a result of using presentation modes such as speech or animation in which current information is often replaced by new information before the learner has time to adequately process or learn the current information. This transient information can be contrasted with permanent information, such as written material in which current information is usually not replaced by new information.

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