EDUCATIONAL PSYCHOLOGIST, *38*(1), 23–31

The Expertise Reversal Effect

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When new information is presented to learners, it must be processed in a severely limited working memory. Learning reduces working memory limitations by enabling the use of schemas, stored in long-term memory, to process information more efficiently. Several instructional techniques have been designed to facilitate schema construction and automation by reducing working memory load. Recently, however, strong evidence has emerged that the effectiveness of these techniques depends very much on levels of learner expertise. Instructional techniques that are highly effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners. We call this phenomenon the expertise reversal effect. In this article, we review the empirical literature on the interaction between instructional techniques and levels of learner experience that led to the identification of the expertise reversal effect.

It is doubtful if anyone would question the need for instructional designers to consider specific characteristics of learners, especially the level of their knowledge or experience in a particular domain. Nevertheless, although the concept of aptitude–treatment interactions has been developed to adapt different instructional treatments to students' particular characteristics, such as knowledge, skills, and learning styles (e.g., Mayer, Stiehl, & Greeno, 1975; Shute & Gluck, 1996; Snow & Lohman, 1984), many instructional design recommendations proceed without an explicit reference to learner knowledge levels. In this article, we survey evidence that a large number of cognitive load theory (CLT) effects that can be used to recommend instructional designs are, in fact, only applicable to learners with very limited experience. With additional experience, specific experimental effects can first disappear and then reverse. As a consequence, the instructional design recommendations that flow from the experimental effects also reverse; for example, if Design A is superior to Design B using novices, with increased expertise, Design B can become superior. We call the reversal of cognitive load effects with expertise the expertise reversal effect. Like all cognitive load effects, it originates from some of the structures that constitute human cognitive architecture. We begin by discussing that architecture.

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SOME ASPECTS OF HUMAN COGNITIVE ARCHITECTURE RELEVANT TO INSTRUCTIONAL DESIGN

Working memory limitations profoundly influence the character of human information processing and, to a considerable extent, shape human cognitive architecture (Sweller, in press). Short-term storage and processing limitations of human memory have been well-known for some time (e.g., Baddeley, 1986; Miller, 1956). Only a few elements (or chunks) of information can be processed at any time without overloading capacity and decreasing the effectiveness of processing. Conversely, long-term memory contains huge amounts of domain-specific knowledge structures that can be described as hierarchically organized schemas that allow us to categorize different problem states and decide the most appropriate solution moves.

Controlled use of schemas requires conscious effort and, therefore, working memory resources. However, after having being sufficiently practiced, schemas can operate under automatic rather than controlled processing (Kotovsky, Hayes, & Simon, 1985; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automatic processing of schemas requires minimal working memory resources and allows problem solving to proceed with minimal effort.

CLT (see Sweller, 1999, and Sweller, van Merriënboer, & Paas, 1998, for recent reviews) is based on the assumption that schema construction and automation are the major goals of instruction, but those goals can be thwarted by the limited capacity of working memory. Because of the limited capacity working memory, the proper allocation of available cognitive resources is essential to learning. If a learner has to expend limited resources on activities not directly related to schema construction and automation, learning may be inhibited.

A learner's level of expertise is a critical factor in determining what information is relevant for the learner and what information is attended to (e.g., Chi & Glaser, 1985). A schema-based approach has been successfully used to explain differences between expert and novice learners (Chi, Feltovich, & Glaser, 1981; Reimann & Chi, 1989). Experts possess a large (potentially unlimited) number of domain-specific schemas. Hierarchically organized schemas represent experts' knowledge in the domain and allow experts to categorize multiple elements of related information as a single, higher level element. When confronted with a specific configuration of elements, experts are able to recognize the pattern as a familiar schema and treat (and act on) the whole configuration as a single unit. When brought into working memory, a single, high-level element requires considerably less working memory capacity for processing than the many low-level elements it incorporates, thus reducing the burden on working memory. As a consequence, acquired schemas, held in long-term memory, allow experts to avoid processing overwhelming amounts of information and effectively reduce the burden on limited capacity working memory. In addition, as already mentioned, experts are able to bypass working memory capacity limitations by having many of their schemas highly automated due to extensive practice. It is clear from this brief discussion that increasing one's level of expertise in a domain is a major means of reducing working memory load.

HOW EXPERTISE CAN ALTER RELATIVE INSTRUCTIONAL EFFECTIVENESS

The level of learner experience in a domain primarily influences the extent to which schemas can be brought into working memory to organize current information. Novices lack sophisticated schemas associated with a task or situation at hand. For these inexperienced learners, no guidance for handling a given situation or task is provided by relevant schemas in long-term memory. Instructional guidance can act as a substitute for missing schemas and, if effective, act as a means of constructing schemas. Effective instruction directly provides instructional guidance while minimizing working memory load (Sweller, 1999; Sweller et al., 1998). If the instructional presentation fails to provide necessary guidance, learners will have to resort to problem-solving search strategies that are cognitively inefficient because they impose a heavy working memory load.

In contrast, experts bring their activated schemas to the process of constructing mental representations of a situation or task. They may not need any additional instructional guidance because their schemas provide full guidance. If, nevertheless, instruction provides information designed to assist learners in constructing appropriate mental representations, and experts are unable to avoid attending to this information, there will be an overlap between the schema-based and the redundant instruction-based components of guidance. Both types of guidance will be available for dealing with the same units of information. In this case, many learners are likely to attempt to relate the overlapping components. Cross-referencing and integration of related redundant components will require additional working memory resources and might cause a cognitive overload. This additional cognitive load may be imposed even if a learner recognizes the instructional materials to be redundant and so decides to ignore that information as best he or she can. Redundant information is frequently difficult to ignore. Such nonoptimal processing of information might result in the failure of an instructional procedure. The involvement of different (schema-based and instruction-based) cognitive constructs for dealing with the same units of information may consume sufficient resources to cause cognitive overload compared with instruction that relies more heavily on preexisting schemas for guidance. For more experienced learners, rather than risking conflict between schemas and instruction-based guidance, it may be preferable to eliminate the instruction-based guidance. As a consequence, instructional guidance, which may be essential for novices, may have negative consequences for more experienced learners. When an instructional design that includes guidance is beneficial for novices (resulting in better performance when compared with performance of novices who receive a format wherein such guidance is omitted) but disadvantageous for more expert learners (resulting in poorer performance when compared with performance of experts who receive a format wherein such guidance is omitted), we have an example of the expertise reversal effect. In the following sections, we review a series of empirical studies that were designed to test conditions when expertise reversal might be observed.

INTERACTIONS BETWEEN LEVELS OF EXPERTISE AND THE SPLIT-ATTENTION AND REDUNDANCY EFFECTS

When dealing with two or more related sources of information (e.g., text and diagrams), it is often necessary to integrate mentally corresponding representations (verbal and pictorial) to construct a relevant schema and achieve understanding. When different sources of information are separated in space (e.g., text located separately from diagrams) or time (e.g., text presented after or before the diagrams are displayed), this process of information integration may place an unnecessary strain on limited working memory resources. Intensive search-and-match processes may be involved in cross-referencing the representations. These search-and-match processes may severely interfere with constructing integrated schemas, thus increasing the burden on working memory and hindering learning.

Physically integrated presentation formats have been suggested as an alternative to split-source instructions (Chandler & Sweller, 1991, 1992, 1996; Mayer & Anderson, 1991, 1992; Mayer & Gallini, 1990; Sweller, Chandler, Tierney, & Cooper, 1990; Tarmizi & Sweller, 1988; Ward & Sweller, 1990). With an integrated format, sections of text are directly embedded onto the diagram in close proximity to corresponding components of the diagram and presented simultaneously with the diagram. Integration of related elements of diagrams and text reduces the visual search, thus decreasing the burden on working memory. Superiority of physically integrated materials that do not require split attention over unintegrated materials that do require split attention and mental integration before they can be understood provides an example of the split-attention effect.

Physical integration of two or more sources of information to reduce split attention and cognitive load is important if the sources of information are essential in the sense that they are not intelligible in isolation for a particular learner. Alternatively, if the sources are intelligible in isolation with one source unnecessary, elimination rather than physical integration of the redundant source is preferable. Superiority of materials with a redundant source of information eliminated over materials containing both sources of information provides an example of the redundancy effect. For example, Chandler and Sweller (1991) found that a diagram alone was superior to a diagram plus text that recapitulated the information in the diagram. Craig, Gholson, and Driscoll (2002), Kalyuga, Chandler, and Sweller (2000), and Mayer, Heiser, and Lonn (2001) found that identical visual and auditory text was less effective than the auditory text alone.

Whether two sources of information are unintelligible in isolation and so require integration or whether one source is redundant and so should be eliminated does not depend just on the nature of the information, it also depends on the expertise of the learner. A source of information that is essential for a novice may be redundant for someone with more domain-specific knowledge. As a consequence, external integration of several sources of information as a means of decreasing working memory load associated with mental integration may be important for novices but may not be effective with more expert learners. Some information in an instructional presentation may be redundant for more experienced learners. In the physically integrated format, processing this information cannot be avoided and integration of redundant information with learners' schemas might impose an additional cognitive load that may interfere with learning due to the redundancy effect. Attending to and integrating redundant information with available schemas requires cognitive resources that consequently may not be available for the construction and refinement of new schemas. Thus, elimination rather than integration of redundant sources of information might be beneficial for learning in the case of more experienced learners.

Kalyuga, Chandler, and Sweller (1998) found that inexperienced electrical trainees benefitted from textual explanations integrated into the diagrams of electrical circuits (to reduce split attention). They were not able to comprehend a diagram-only format. However, more experienced trainees performed significantly better with the electrical circuit diagram-only format. More experienced trainees also reported less mental effort associated with studying the diagram-only format. For these more knowledgeable learners, the textual information, rather than being essential and so best integrated with the diagram, was redundant and so best eliminated. The split-attention effect for novices was replaced by the redundancy effect for experts. An instructional design that included explanatory material in an integrated format was superior for novices but inferior for more knowledgeable learners, thus demonstrating an expertise reversal effect.

Using textual materials, Yeung, Jin, and Sweller (1998) also obtained this effect. Integrating explanatory notes into the primary text assisted learners with low levels of language competence. The same format retarded learning for more knowledgeable learners because the integrated notes, although redundant, were difficult to ignore when integrated into the primary text.

TEXT PROCESSING AND THE EXPERTISE REVERSAL EFFECT

McNamara, Kintsch, Songer, and Kintsch's (1996) research is also related to the expertise reversal effect. McNamara et al. (1996) found that additions to an original instructional text in high school biology intended to increase text coherence were beneficial only for low-knowledge readers. High-knowledge readers benefitted most from using the original, minimally coherent format text rather than the enhanced text.

McNamara et al.'s (1996) findings are similar to those of Kalyuga et al. (1998) and Yeung et al. (1998) already described. Less knowledgeable learners benefitted from additional explanatory material, but more knowledgeable learners were better able to process the material without the additions. Although the results of the sets of studies are very similar, the interpretations are quite different. Kalyuga et al. (1998) and Yeung et al. (1998) proposed that, for experienced learners, eliminating redundant material is advantageous because it reduces the cognitive load associated with processing redundant information in working memory. McNamara et al. (1996) argued that high-knowledge students benefitted from the minimally coherent text because it forced them to engage actively in additional processing of the text.

The use of subjective mental ratings can be used to provide information relevant to these conflicting interpretations. If, as

McNamara et al. argued, high-knowledge students benefit when information is omitted because of the additional active processing required, then such additional processing should increase cognitive load. Yet Kalyuga et al. (1998) and Yeung et al. (1998) found that experienced learners studying a minimal format reported lower estimates of mental load compared to formats with redundant information. According to this explanation, text coherence depends on a learner's expertise. Text that is minimally coherent for novices may well be fully coherent for experts. Providing additional text is redundant for experts and will have negative rather than positive effects, thus demonstrating the expertise reversal effect. . Consequently, McNamara et al.'s (1996) results may be due to the expertise reversal effect rather than due to experts' being forced to engage actively in the processing of text with reduced information.

INTERACTIONS BETWEEN LEVELS OF EXPERTISE AND THE MODALITY AND REDUNDANCY EFFECTS

Using a combination of both auditory and visual sources of information is an alternative way of dealing with split attention. According to dual-processing models of memory and information processing (Baddeley, 1986; Paivio, 1990; Penney, 1989; Schneider & Detweiler, 1987), the capacity to process information is distributed over several partly independent subsystems. As a consequence, effective working memory capacity can be increased by presenting some information in an auditory and some in a visual modality. For example, the negative consequences of split attention may be ameliorated by associating a visual diagram with spoken rather than written text. Integration of the audio and visual information may not overload working memory if its capacity is effectively expanded by using a dual-mode presentation. Many studies (Mayer, 1997; Mayer & Moreno, 1998; Mousavi, Low, & Sweller, 1995; Tindall-Ford, Chandler, & Sweller, 1997) have demonstrated that learners can integrate words and diagrams more easily when the words are presented in auditory form rather than visually, providing an example of the instructional modality effect. As was the case for physical integration in visual-only presentations, dual-mode presentations are effective if an extensive visual search, essential to coordinate auditory and visual information, is eliminated. For example, to reduce visual search, Jeung, Chandler, and Sweller (1997) used visual flashing indicators as pointers to the part of a diagram to which the auditory information referred.

However, auditory explanations may also become redundant when presented to more experienced learners. Kalyuga et al. (2000) demonstrated that if experienced learners attend to the auditory explanations, learning might be inhibited. In a set of experiments with instructions on using industrial manufacturing machinery, inexperienced learners in a domain clearly benefitted most from studying a visually presented diagram combined with simultaneously presented auditory explanations. After additional training, the relative advantage of the audio text disappeared whereas the effectiveness of the diagram-only condition increased. Specifically, when the same students became even more experienced after further intensive training in the domain, a substantial advantage of a diagram-only condition over a diagram with audio text condition was obtained, reversing the results of the first experiment. Subjective mental load ratings collected immediately after each stage of the experimental training clearly supported a cognitive load interpretation of the results. Thus, the level of learner experience effectively related the modality effect to the redundancy effect in a similar way to the relations between split attention and redundancy in the Kalyuga et al. (1998) and Yeung et al. (1998) studies, again demonstrating an expertise reversal effect.

INTERACTIONS BETWEEN LEVELS OF EXPERTISE AND THE WORKED EXAMPLE EFFECT

Worked examples consisting of a problem statement followed by explanations of all solution details represent a case of fully guided instruction. Exploratory learning environments, discovery learning, or problem solving, however, represent a form of less or even relatively unguided instruction. A considerable number of studies have demonstrated that properly designed worked examples are often a better instructional alternative than conventional problem-solving techniques (Carrol, 1994; Cooper & Sweller, 1987; Paas, 1992; Paas & van Merriënboer, 1994; Quilici & Mayer, 1996; Sweller & Cooper, 1985; Trafton & Reiser, 1993). Similarly, Rieber and Parmley (1995) demonstrated that when adults learned laws of mechanics from unstructured simulations (designed as free exploration), the results were significantly worse than those for an example-based, tutorial condition.

When solving unfamiliar problems, learners normally use a means–ends search strategy directed toward reducing differences between current and goal problem states by using suitable operators. These activities are unrelated to schema construction and automation and are cognitively costly because they impose a heavy working memory load (Sweller, 1988). Providing worked examples instead of problems eliminates the means–ends search and directs a learner's attention toward a problem state and its associated moves. Of course, worked examples should be appropriately structured to eliminate an unnecessary cognitive load due to, for example, split-attention effects (as discussed earlier). Otherwise, worked examples can be as demanding of cognitive resources as solving problems by a means–ends analysis (e.g., Sweller et al., 1990).

As learners' experience in a domain increases, solving a problem may not require a means–ends search and its associated working memory load due to partially, or even fully, constructed schemas. When a problem can be solved relatively effortlessly, analyzing a redundant worked example and integrating it with previously acquired schemas in working memory may impose a greater cognitive load than problem solving. Under these circumstances, practice in problem solving may result in more effective learning than studying worked examples because solving problems may adequately facilitate further schema construction and automation. Although appropriately structured worked examples might be beneficial for learners who are inexperienced in a domain, similarly structured worked examples might become redundant once learners achieve sufficient levels of experience.

Kalyuga, Chandler, Tuovinen, and Sweller's (2001) experiments confirmed these suggestions. Inexperienced mechanical trade apprentices were presented with either a series of worked examples to study or problems to solve. On subsequent tests, inexperienced trainees benefitted most from the worked examples condition. Trainees who studied worked examples performed better with lower ratings of mental load than similar trainees who solved problems, duplicating a conventional worked example effect. With more experience in the domain, the superiority of worked examples disappeared. Eventually, with sufficient experience, additional learning was facilitated more by problem solving than through studying worked examples. The worked examples became redundant and problem solving proved superior, demonstrating another expertise reversal effect.

Tuovinen and Sweller (1999) provided additional data supporting the hypothesis. They compared exploration and worked examples instructional approaches to learning to use a database program. Students with no previous familiarity with databases benefitted more from worked examples. For students who had previous familiarity with the domain, there were no differences between the two instructional strategies.

Lastly, Kalyuga, Chandler, and Sweller (2001) compared a series of worked examples with an exploratory-based learning environment that allowed participants to explore the same material on their own. Two levels of task difficulty were used: (a) simple tasks with a very limited problem space, resulting in a small number of possible options to explore; and (b) complex tasks with a relatively larger problem space, giving numerous options to explore. There were only minimal differences between the two instructional procedures on simple tasks. For complex tasks, inexperienced trainees clearly benefitted most from the worked examples procedure. The group presented with worked examples performed significantly better with lower ratings of mental load than similar trainees who studied the exploratory procedure. When participants became more experienced in the domain after specifically designed training sessions, the advantage of the worked examples condition disappeared. Thus, as the level of experience was raised, the exploratory group improved more rapidly than the worked examples group, exhibiting an expertise reversal pattern.

In all of the experiments described here, inexperienced learners benefitted most from an instructional procedure that placed a heavy emphasis on guidance. Any additional instructional guidance (e.g., indicating a goal or subgoals associated with a task, suggesting a strategy to use, providing solution examples, etc.) should reduce cognitive load for inexperienced learners, especially in the case of structurally complex instructional materials. At the same time, additional instructional guidance might be redundant for more experienced learners and require additional working memory resources to integrate the instructional guidance with learners' available schemas that provide essentially the same guidance. A minimal guidance format might be more beneficial for these learners because they are able to use their schema-based knowledge as guidance in constructing integrated mental representations without overloading working memory.

There is substantial additional evidence indicating that instructional designs should take into account levels of learner expertise. In a series of studies, Renkl (1997) and Renkl, Atkinson, and Maier (2000) consistently demonstrated that detailed worked examples were most appropriate when presented to novices, but they should be gradually faded out with increased levels of learner knowledge and be replaced by problems (also see Renkl & Atkinson, 2003). Furthermore, Renkl, Atkinson, Maier, and Staley (2002) found that a fading out procedure was superior to an abrupt switch from worked examples to problems. The advantage of reducing guidance with increases in expertise is an example of the guidance-fading effect. This effect provides a direct instructional application that is in accord with the expertise reversal effect.

Having analyzed extensive previous work on multimedia learning (e.g., Mayer, 1999; Mayer & Gallini, 1990; Mayer, Steinhoff, Bower, & Mars, 1995), Mayer (2001) found a stable pattern of results indicating that inexperienced learners benefitted far more from instructional presentations designed to provide a better support for cognitive processes than high-knowledge learners. Mayer called this principle the "individual differences principle" (p. 161). High-knowledge learners' use of available prior knowledge to compensate for a lack of instructional guidance was suggested as the main theoretical rationale for the principle. These results also are in accord with the expertise reversal effect when the effect is generated by the use of worked examples with more experienced learners. Inexperienced learners require the support for cognitive processes provided by worked examples. More experienced learners find that additional support redundant; thus, processing worked examples interferes with rather than supports learning.

INTERACTIONS BETWEEN LEVELS OF EXPERTISE AND THE ISOLATED OR INTERACTING ELEMENTS EFFECT

Some material imposes an intrinsically high cognitive load because the elements that must be learned interact and so cannot be processed in isolation without compromising understanding (Sweller, 1994; Sweller & Chandler, 1994). To understand such structurally complex instructional materials, learners must process many interacting elements of information simultaneously in working memory where *understanding* is defined as the ability to process all necessary interacting elements in working memory simultaneously. The degree of element interactivity for a given instructional presentation can be assessed as the number of elements that must be attended to in order to understand the instruction. For low-element interactivity material (e.g., learning the translation of single words in a second language), each element can be learned individually and does not impose a heavy cognitive load. For high-element interactivity material (e.g., learning allowable word orders in English), individual elements interact and so must be learned simultaneously rather than as individual elements. A heavy working memory load can result. However, an assessment of element interactivity is always relative to the level of expertise of an intended learner. If the learner holds an appropriate set of previously acquired domain-specific schemas, the whole set of interacting elements may be incorporated into a schema and regarded as a single element (e.g., common language syntactic structures for native speakers). Conversely, a novice learner may need to attend to each of the elements and learn all interactions between the elements individually (e.g., syntactic structures of a foreign language for beginners). If element interactivity is sufficiently high for the learner, this mental activity will overload the limited capacity of working memory and cause a learning failure.

Once the individual has learned all the interactions between the elements, the learner will have acquired a new schema. This schema can now act as a single element every time the learner encounters similar tasks or situations. At this level of learner expertise, element interactivity is reduced to the minimum. Consequently, more experienced learners will be able to use their schemas to group together at least some of the elements of incoming information. Because some of the interacting elements are incorporated in schemas, more experienced learners can process these elements in working memory as a single element, thus keeping cognitive load within the confines of working memory. For these more experienced learners, understanding is less likely to be a problem.

How can novices acquire the schemas necessary to allow the processing of very high-element interactivity material if they cannot process all of the elements in working memory simultaneously and if those interacting elements cannot be processed in isolation because they interact? Pollock, Chandler, and Sweller (2002) suggested an isolated elements instructional technique that allows novices to circumvent working memory limitations by initially presenting complex material as a collection of individual, isolated elements of information. If element interactivity is artificially reduced in this way, some partial rudimentary schemas for the presented information may be developed first, allowing novice learners to reduce working memory load during a subsequent attempt to learn from the original, high-element interactivity material. Note that the isolated elements format is not aimed at providing understanding at the initial stage of instruction because critical relations are artificially eliminated. Because understanding very high-element interactivity material is impossible for novices until they have acquired schemas that incorporate the interacting elements, the presentation of the material in a form that does not permit understanding is assumed not to have negative consequences. This initial learning without understanding is assumed to be compensated for by a better level of understanding at the second phase of instruction.

In Pollock et al.'s (2002) experiments, a mixed instructional method (isolated elements followed by interacting elements instruction) was superior to the conventional method (interacting elements instruction during both stages) for novice learners. These learners also reported lower subjective ratings of mental load associated while studying mixed instructional formats. However, the difference between the two methods disappeared when they were used with learners who had experience in the relevant knowledge domains. The mixed method of instruction did not provide any benefits to learners who already possessed rudimentary schemas and thus did not experience an excessively heavy cognitive load when processing the original interacting elements instruction. The experienced learners' subjective mental effort ratings of the instructional conditions did not differ, providing further credence to this explanation.

Although a full reversal was not observed in these studies, elimination of the effect was obtained with increases in expertise. Mixed method instructions benefitted only less experienced learners, providing partial evidence for the expertise reversal effect.

In accord with these findings, Mayer and Chandler (2001), using scientific instructional material, found that initially permitting inexperienced learners to control artificially the speed of an animation and thus allowing the assimilation of isolated elements within specific animation frames benefitted learners far more than initially presenting learners with a high-element interactivity animation, which they could not control. When both groups of learners were faced with a second presentation of the high-element interactivity animation and had no control over the speed of the animation, the learners that were allowed to exercise control of the animation initially during the first presentation demonstrated superior learning and transfer of knowledge.

INTERACTIONS BETWEEN LEVELS OF EXPERTISE AND THE IMAGINATION EFFECT

The *imagination effect* (Cooper, Tindall-Ford, Chandler, & Sweller, 2001) occurs when learners asked to imagine the content of instruction learn more than learners simply asked to study the material. In Cooper et al.'s (2001) experiments, two alternative instructional strategies were compared with students learning to use a spreadsheet: (a) studying worked examples or (b) imagining procedures and relations described in instruction. More knowledgeable students who held appropriate prerequisite schemas found imagining procedures and relations more beneficial for learning compared with studying worked examples, whereas less knowledgeable students found imagining procedures and relations had a negative effect compared with studying worked examples. In other words, the effect reversed depending on the expertise of the learners, providing a clear example of the expertise reversal effect.

The process of mental imagining is closely associated with constructing and running mental representations in working memory. Because inexperienced learners have no appropriate schemas to support this process, attempts to engage in imagining are likely to fail. The absence of schemas means that all the relevant elements must be processed as individual elements, and working memory limitations may render that task impossible. If the task is impossible, those who attempt to follow imagination instructions are likely to learn little. However, although experienced learners might lose from attending to redundant instructional guidance provided by studying worked examples, they may well benefit from practice at imagining the task procedure. Their schemas incorporate the interacting elements that less knowledgeable learners must handle individually. As a consequence, more experienced learners should be able to follow imagination instructions without working memory overload. Imagining a procedure or a set of relations may increase the degree of automation of corresponding schemas, thus improving performance. When asked to study worked examples rather than imagine procedures, novices can construct schemas of interacting elements, an essential first step in learning. More expert learners already have such schemas; thus, asking them to study the material is likely to constitute a redundant activity. Imagination instructions benefit more experienced learners compared with study instructions, but study instructions are superior for novices, providing an example of the expertise reversal effect.

CONCLUSIONS

This article was designed to review empirical studies demonstrating the existence of an expertise reversal effect and to show that it has a plausible theoretical explanation within a cognitive load framework. We have suggested that under some conditions, when fully guided instructional material is presented to more experienced learners, a part or all of the provided instructional guidance might be redundant. In contrast, that same material may be essential for less experienced learners. Unless experienced learners can avoid processing redundant units of information, they must integrate and cross-reference this redundant information with their available knowledge schemas. This activity can place an excessive and unnecessary load on limited working memory resources. An instructional format without redundant guidance is likely to be the best instructional format for more experienced learners because all the necessary support for the construction of mental representations in working memory is provided by schema-based knowledge structures held in long-term memory. However, if that guidance is essential for novices, the expertise reversal effect will be obtained. A similar effect also will be obtained if novices must attempt to process very complex, high-element interactivity material or attempt to imagine complex material beyond working memory limits. In both cases, alternative instructional strategies are superior, but that superiority disappears or reverses if more expert learners who can process all of the required elements are presented the instructional material.

The expertise reversal effect has been replicated in multiple studies using a large range of instructional materials and participants. It interacts with many of the cognitive load effects demonstrated over the last 20 years. The most important instructional implication of this effect is that, to be efficient, instructional design should be tailored to the level of experience of intended learners. Without such tailoring, the effectiveness of instructional designs is likely to be random. Indeed, recommendations to use particular designs can be potentially quite counterproductive. In conclusion, we believe the expertise reversal effect is an important phenomenon that has the potential to provide valuable instructional design guidance and, even more important, to reveal aspects of human cognitive architecture that otherwise would remain hidden.

ACKNOWLEDGMENT

The research reported in this article was supported by Grants A00102995, C7980448, and F00103016 from the Australian Research Council to John Sweller, Paul Chandler, and Slava Kalyuga.

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