Effects of Worked Examples on Far Transfer

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Abstract

YOUNG RAN KIM: Effects of Worked Examples on Far Transfer
(Under the direction of Dr. Jeffrey A. Greene)

Increasing students' transfer of problem-solving skills is one of the main goals of instruction. This review focuses on using worked examples as instructional methods to increase students' problem-solving skills in far-transfer tasks. Worked examples are well-known instructional methods from Cognitive Load Theory (CLT). CLT researchers posit that worked examples are effective instructional methods for increasing far transfer of problem-solving skills because they can reduce the burden on working memory by contributing to schema construction and automation, and making cognitive resources available to deal with unfamiliar aspects of the problems. Previous studies have shown the effectiveness of studying worked examples for near transfer compared with engaging in problem solving. Is studying worked examples effective for increasing problem-solving skills for far-transfer tasks as well? I discuss the main findings of studies that have addressed this question. Some researchers have investigated whether adding instructional strategies to worked examples might increase their effectiveness for far transfer. I also review the main findings of these studies. The last question to be addressed is whether studying worked examples is a more effective way of fostering transfer for certain age groups compared with others. In my review of the literature, I found that studies on the effectiveness of worked examples showed diverging findings; employing instructional strategies such as self-explanation prompts, fading procedures, or adding subgoals might enhance the beneficial effect of studying

worked examples on far transfer; and worked examples might be more beneficial for older age groups than younger age groups.

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CHAPTER 1

INTRODUCTION

The world is changing rapidly, and the amount of information being produced every day is ever increasing. Current knowledge quickly becomes outdated. As a consequence, a considerable amount of knowledge that students obtain from their schooling may not be relevant to their future (Barnett & Ceci, 2002). Moreover, education cannot provide everything students need for their future studies and professional careers. Students must develop the ability to transfer.

According to Chi and VanLehn (2012), transfer is the ability to treat a new concept, problem, or phenomenon as similar to one that has been encountered before. When transferring, a person takes knowledge or strategies that were learned in one context, and successfully applies them in a different context. When there is a great deal of similarity between the new setting and the original training setting, near transfer occurs (Schunk, 2012). On the other hand, far transfer occurs when there is little similarity between the two settings.

Without transfer, students can apply what they have learned only within the specific context in which the learning materials were imbedded. This limitation makes learning and teaching highly ineffective, because additional instruction would be required for students to apply the same knowledge in a different context. Thus, creating a learning environment to foster transfer is growing in importance (Engle, 2012). However, a considerable amount of research has shown that helping learners transfer what they have learned is not an easy task (Goldstone & Day, 2012). Given the importance of transfer and the difficulties in fostering students' transfer performance, researchers and educators are exploring how to increase students' performance on transfer.

Worked examples have been investigated as an instructional method to increase transfer. Worked examples include three components: the formulation of a definite problem, the solution steps (i.e., operators), and the final solution itself (Wittwer & Renkl, 2010). The following is an example based on Sweller, Ayres, and Kalyuga (2011). For the question Solve $(x + 12)/3 = 8$ for x, learners are presented with the following worked-out solution:

$$(x + 12)/3 = 8$$

$$x + 12 = 24$$

$$x = 24 - 12$$

$$x = 12$$

According to van Merriënboer and Sweller (2005), worked examples increase the likelihood of transfer by allowing working memory to be devoted to understanding solution procedures, building relevant schemata, and automating them, rather than searching for the solution. Also, worked examples enhance transfer by making more working memory capacity available to deal with the unfamiliar aspects of problems.

A number of studies have explored whether worked examples are an effective way of improving transfer, and there are reviews of these studies (e.g., Atkinson, Derry, Renkl, & Wortham, 2000; Atkinson & Renkl, 2007; Van Gog & Rummel, 2010). However, no comprehensive literature synthesis focused on far transfer exists. Therefore, the goal of this review is to provide an overview of the research on the effectiveness of worked examples for fostering far transfer. Specifically, I addressed the following research questions:

- Does studying worked examples improve performance on far-transfer tests?
- What instructional strategies can be used to enhance the effect of studying worked examples on far transfer?
- Is studying worked examples an effective way of fostering transfer for some age groups as compared to others?

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CHAPTER 2

THEORETICAL BACKGROUND

Many researchers have investigated the effectiveness of worked examples as an instructional method to enhance transfer within cognitive load theory (CLT; Sweller, van Merrienboer, & Paas, 1998). In this section, I discuss how CLT approaches transfer and lack of transfer, what instructional implications can be drawn from CLT, and the effectiveness of worked examples for transfer. Also, I investigate the developmental aspects of limits to working memory in order to discuss whether studying worked examples is a better way of increasing transfer for certain age groups as compared to others.

Cognitive Load Theory and Transfer

Cognitive load theory. CLT provides a framework for understanding why transfer does not occur. CLT focuses on devising instructional methods that are compatible with human cognitive architecture in order to overcome the limitations of working memory and to facilitate schema construction in long-term memory (Kirschner, Kester, & Corbalan, 2011). Cognitive load can be defined as a multidimensional construct representing the burden imposed on the learners' cognitive system when performing a particular task (Paas & van Merrienboer, 1994a). According to CLT, transfer tasks, which include unfamiliar pieces of information, can induce high cognitive load on working memory. This load prevents effective processing of information in working memory, which in turn reduces performance on transfer tasks.

CLT is based on information processing theory (IPT). IPT addresses how humans process, store, and retrieve information using a cognitive system (Schunk, 2012). It views humans as processors of information and their minds as information-processing systems. While Behaviorism focuses on external conditions provoking responses, IPT theorists pay more attention to internal mental processes intervening between stimuli and responses. They emphasize learners' active roles in obtaining and processing information.

According to IPT, learners selectively attend to information around them and actively process it in their working memory through transformation, rehearsal, organization, or by relating it to knowledge that they already have (Schunk, 2012). After information is processed in working memory, it is stored in long-term memory According to Schunk, IPT theorists have different opinions regarding the cognitive processes that occur and their importance, but they share two common assumptions. One assumption is that they think information processing occurs when people receive information and produce a response to it. The other assumption is that human's information processing is similar to that of computers. CLT shares these common assumptions with IPT in that it assumes that information processing occurs when people receive information. Also, CLT has similar aspects regarding the roles and characteristics of working memory and long-term memory.

Like IPT, CLT posits that working memory, where information is processed and organized for storage, has a limited capacity and duration. Working memory holds about seven chunks of information, plus or minus two (Miller, 1956). This capacity can be even lower when people are asked to process information in addition to retaining it. For example, when given numbers and asked to calculate them, people can memorize only two or three digits, instead of seven. Working memory has limitations on duration as well. Almost all information stored in working memory will be lost unless it is rehearsed (Peterson & Peterson, 1959), or related to knowledge in long-term memory (van Merriënboer & Sweller, 2005). Limitations in working memory occur when people manipulate information in a new domain without relevant schemata in their long-term memory (van Merriënboer & Sweller, 2005). Because of the limitations of working memory, CLT researchers argue that any cognitive load should be minimized when it is not relevant to schema construction (i.e., learning).

Three different kinds of cognitive load are identified in CLT: intrinsic, extraneous, and germane (van Merriënboer & Sweller, 2005). Intrinsic load is generated by the interactivity of different elements within learning materials. Materials with high interactivity are difficult to understand because interacting elements must be processed simultaneously (Paas, Renkl, & Sweller, 2003). Calculating the velocity of an object dropped based on height is an example of a procedure having high intrinsic load due to high interactivity. To understand how to calculate the velocity, students need to understand the principle of conservation of energy, concepts like kinetic energy and potential energy, and equations for height and velocity. The interactivity of these elements cannot be changed by instructional manipulations because it is intrinsic to the learning materials (van Merriënboer & Sweller, 2005). Intrinsic load can be reduced in some situations by omitting some interacting elements of information, but this inhibits sophisticated understanding (Paas et al., 2003). Eventually, simultaneous processing of all essential interacting elements is necessary for complete understanding to occur.

The ways in which information is presented to learners and learning activities can also cause cognitive load. When cognitive demands from these sources contribute to learning, it is referred to as germane load. Self-explanation, which involves explanation by learners to infer information that is not directly given in the learning materials (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), would be considered germane load because it contributes to schema construction even though it increases cognitive load (Renkl & Atkinson, 2003). In contrast, when the presentation of information or learning activities do not contribute to learning, extraneous load is induced. For example, instructional methods that require learners to search for a solution generate extraneous load because they occupy learners' working memory capacity without contributing to schema construction or automation (Paas et al., 2003).

CLT assumes that cognitive load can be reduced when learners have relevant schemata. According to schema theory, people store knowledge in the form of schemata (Matlin, 2009). People encode generalized knowledge about a situation or an event and use this generic knowledge to recognize and understand what happens around them. This generalized knowledge is called schemata. Schemata are large networks representing categorical knowledge including a structure composed of slots for information (Anderson, 2000). Slots correspond to various attributes that members of a category have. For example, values like wood, brick, or stone are stored in the slot for materials in the schema for house. Schemata are abstract because they encode what is generally true. They are abstracted, generalized knowledge obtained from experiences.

Schema theory is helpful in explaining how people process complex information (Matlin, 2009). Schemata organize and store elements of information according to their use

(Chi, Glaser, & Ress, 1982). Many elements of information can be chunked into a single element in schemata, and low level elements belonging to a higher level schema are treated as one entity in working memory. For example, according to Schank and Abelson (1977), under the schema for going to a restaurant, specific events like entering a restaurant, being led to a table, deciding on an order, eating food, and paying for a bill are included. The schema allows people to process these events as one entity (i.e., going to a restaurant) without consciously paying attention to individual aspects contained in the schema. In this way, schemata reduce the burden on working memory while making the processing of information more efficient. Also, this is how the number of elements of information needed to be processed in working memory can be reduced, increasing the amount of information that working memory can process simultaneously. On the other hand, when schemata do not exist in long-term memory, information is randomly organized. This increases the number of elements needed to be organized, thus placing a heavy load on limited working memory (van Merriënboer & Sweller, 2005).

Besides reducing load on working memory, schemata also can enhance problem-solving skills in a variety of ways. Acquired schemata allow learners to recognize which category a problem belongs to and what operations are necessary to reach the solution within that category (Paas, 1994). Also, learners can use acquired schemata as analogies in new problem-solving situations when they do not have task-specific schemata. Schemata consisting of the common elements of related problems provide analogies to generate reasonable inferences about the target problem (Cooper & Sweller, 1987). Learners can use their existing schemata as general procedures and map them onto problem situations to generate new solutions (van Merriënboer & Paas, 1990). For these reasons, schema construction is considered an important factor for increasing problem-solving skills on transfer tasks.

Automation is also another prerequisite for transfer of cognitive skills. Automation is defined as a task-specific procedure that can directly control problem-solving behaviors without conscious processing (van Merriënboer & Paas, 1990). When problem-solving procedures become automated, problem solvers can apply these procedures without the need for processing them in working memory (van Merriënboer & Sweller, 2005). Thus, automation leaves more working memory capacity available to deal with unfamiliar aspects of a problem (Cooper & Sweller, 1987). Also, more working memory capacity will be available for reasoning processes that make a skill more flexible to contextual or structural changes of the problem (Renkl, 2011). This is why automation is regarded as necessary to improve problem- solving skills in transfer tests (van Merriënboer & Sweller, 2005).

Schemata help students overcome the limitations of working memory and process more information. This is why schema construction and automation play an important role in improving problem-solving skills on transfer tasks. CLT suggests that any cognitive load imposed on working memory should be minimized when it is not relevant to schema construction and automation to promote transfer. In the next section, I discuss how CLT explains the effectiveness of worked examples in terms of fostering far transfer.

Worked Example Effect

Research on CLT has focused on developing instructional methods to help learners devote their limited working memory capacity primarily to building relevant schemata and automating them to increase learners' ability to transfer. One of the earliest and the best known instructional techniques within CLT is worked examples (Paas et al., 2003).

According to CLT, worked examples can improve transfer by reducing extraneous load and instead increasing germane load. Also, by presenting solution procedures, they make more working memory capacity available to deal with unfamiliar aspects of the problems.

Worked examples might also enhance transfer by enabling learners to recognize the deep structure of a problem regardless of its surface features. Transfer is more likely to occur when students can see deep structure of a problem (Day & Goldstone, 2010). Day and Goldstone explained transfer by employing the concept of surface features and deep structure. Surface features indicate what is salient in a problem statement or situation such as literal objects or entities, whereas deep structure refers to less salient aspects such as problem solving procedures, schemata, or conceptual and abstract rules (Chi & VanLehn, 2012). The ability to see commonalities in deep structure between cases play an important role in meaningful and productive transfer. Previous research has shown that emphasizing commonalities in deep structure between cases can increase students' transfer performance (e.g., Brown, Kane, & Echols, 1986; Catrambone, 1996; Loewenstein & Gentner, 2005; Son et al., 2010). For example, in an experiment conducted by Brown et al. (1986), students' far transfer performance was greatly improved when they were asked to answer questions stressing underlying goal structure.

Finding structural commonalities between the training problem and the target problem is important for transfer. As discussed previously, worked examples contribute to schema construction by presenting a procedure to reach the solution. This schema, in turn, might enable students to see the deep structure of the training problem and the target problem and find commonalties between them. Hence, worked examples presumably increase transfer performance.

In contrast, engaging in solving a problem can hinder transfer. When solving problems without relevant schemata, learners adopt a means-ends analysis strategy (Sweller et al., 1998). This means that learners pay attention simultaneously to the current problem state, the goal state, and differences between them to find a solution. This means-ends analysis strategy places a huge burden on their limited working memory because they have to process many aspects of the problem. It not only lowers the amount of information working memory can process but also leaves little space in their limited working memory for schema construction and automation. Since this means-ends analysis strategy uses working memory capacity without schema construction and automation, it induces extraneous load, and less working memory capacity is available for germane load. This is why problem solving is a less effective and efficient instructional method than worked examples in terms of increasing students' performance on transfer problems in CLT.

CLT explains the effectiveness of instructional methods for transfer mainly in terms of their effectiveness in reducing cognitive load on working memory. CLT elucidates how transfer occurs without considering the types of knowledge constructed from learning tasks. Even though CLT does not consider knowledge structures in explaining transfer, the types of knowledge constructed from the learning tasks seem to be important in determining the degree of transfer.

Three different types of knowledge may be formed by studying worked examples: conceptual, procedural, and conditional knowledge. Conceptual knowledge can be defined as understanding how pieces of knowledge in a domain are related to each other or understanding the principles that rule the domain (Rittle-Jonson & Alibali, 1999). Procedural knowledge refers to the ability to apply action sequences to solve problems. Conditional knowledge is knowing when and why to use forms of declarative and procedural knowledge (Gagné, 1985).

By studying worked examples, these three types of knowledge can be developed. For example, procedural knowledge may be generated when learners internalize solution procedures that demonstrate how to solve a problem in a step by step manner. Worked examples may also help students build conditional knowledge because students are able to distinguish which category a problem belongs to and when to apply appropriate solution procedures. Furthermore, when students acquire principles or rules governing solution steps, they may gain conceptual knowledge.

According to Barnett and Ceci (2002), the degree of transfer in problem solving may depend on a form of knowledge representation. From the learning tasks, students can acquire a specific knowledge structure bound to certain problem situations (e.g., procedural knowledge). They also can acquire a more general representation of knowledge such as problem-solving heuristic or a principle (e.g., conceptual knowledge). An example of a specific knowledge structure would be an equation for calculating proportions. The general representation of knowledge would be statistical principles (Fong Krantz, & Nisbett, 1986) or hierarchical classification (Herrnstein, Nickerson, de Sanchez, & Swets, 1986).

A more general representation of knowledge is likely to lead to better transfer to novel contexts (Barnett & Ceci, 2002). This means that when students have conceptual knowledge for solution steps, transfer is more likely occur. This might be because conceptual understanding affects generation and adoption of solution procedures (Rittle-Jonson & Alibali, 1999). In previous studies, students who had better conceptual knowledge showed better procedural skills (e.g., Cauley, 1988; Hiebert & Wearne, 1996).

Obtaining conceptual knowledge for solution steps may require learners' active processing of solution steps because they need to understand how rules or principles are applied in the development of the solution steps. In order to facilitate principled understanding for solution steps, researchers have employed a variety of instructional strategies such as self-explanation prompts, incomplete solution procedures, providing instructional explanations, or emphasizing subgoals. Worked examples are meant to reduce cognitive load, but these instructional strategies can actually increase cognitive load. However, this increased load due to instructional strategies would be considered germane load, and therefore ultimately beneficial load, since they presumably contribute to schema construction and automation.

Previous studies on worked examples have shown that studying worked examples is more effective for increasing students' problem-solving skills than engaging in problem solving, especially for novices (e.g., Cooper & Sweller, 1987; Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Paas, 1992; Paas & van Merriënboer, 1994a; Sweller, Chandler, Tierney, & Cooper, 1990). Students showed better performance when they studied worked examples than when they solved problems without worked examples. This worked example effect is particularly strong for learners with low prior knowledge in the domain (Kalyuga et al., 2000, 2001, 2003). Also, using worked examples is especially effective for teaching well-structured domains like mathematics and science (Pashler, Bain et al., 2007). This may be because solution steps can be presented in a systematic manner in these domains, which, in turn, can enhance the effectiveness of studying worked examples.

A report by Pashler et al. (2007) showed how the effect of studying worked examples on far transfer can be further enhanced. For example, studying worked examples seems to be more effective when they are interleaved with problem-solving exercises. Students showed better achievement when they studied worked examples alternated with relevant problems than when they studied a series of worked examples before they solved a series of problems (Trafton & Reiser, 1993). As students' expertise increases, however, it is better to fade out solution steps and increase problem solving demands by requiring them to fill in these steps (Kalyuga et al., 2001). This means that fading worked examples is more effective than using traditional worked examples, where all solution steps are presented simultaneously. Also, labeling groups of steps seems to increase their effectiveness (Catrambone, 1996).

According to CLT, worked examples are effective methods for promoting transfer. Worked examples enhance transfer by minimizing extraneous load and optimizing germane load. They also leave more working memory capacity to handle novel aspects of the problem. Furthermore, worked examples might improve transfer by enabling learners to discern deep structure of the problem regardless of its surface features through schema construction.

Transfer is more likely to occur when students have conceptual knowledge for worked examples because they can enhance generation and adoption of solution procedures. Instructional strategies such as self-explanation prompts, incomplete solution procedures, providing instructional explanations, or emphasizing subgoals might contribute to facilitating transfer by helping learners obtain conceptual knowledge for solution procedures. In the next section, I will discuss the working memory capacity of different age groups differs from each other, and whether studying worked examples can bring more positive effects for some age groups than other groups.

Developmental Aspects of Limits to Working Memory

Toddlers have limited working memory, but its capacity improves dramatically during childhood (Swanson, 1999). Development of working memory can occur in two aspects: capacity and processing speed (Kail & Cavanaugh, 2004). Memory span is used to measure working memory capacity. A 2-year-old can recall two numbers in a row on average, while a 9-year-old can recall about six numbers. The level of working memory capacity reaches that of adults during adolescence. Working memory development also occurs in its processing speed. In an experiment conducted by Kail (2004), 8-year-olds needed about one-third of a second to press a button in response to a visual stimulus, while it took one-quarter of a second for 12-year-olds. Processing speed becomes almost like that of adults during adolescence as well. Even though it increases with age, children's working memory seems to be limited in its capacity and speed.

Memory span, which represents the capacity of working memory, might play an important role in learning problem-solving skills. This is because memory span is closely related to many academic skills, such as vocabulary development, reading, or general intellectual ability (Henry, 2012). However, children's memory span has not yet reached its full potential; thus they might have more difficulties in learning problem-solving skills compared with adolescents and adults. This is especially because children are highly likely to not yet have the relevant schemata, which assist in the information processing of working memory. The lack of schemata might increases dependency on working memory for information processing. Hence, an efficient instructional method that can optimize the processing of information in working memory would be more beneficial for children, especially in the acquisition of complex skills, because they require both the ability to retain and manipulate different types of information. This means that worked examples, which can optimize the use of working memory for schema construction and automation, might be more beneficial for children than adults. In the next section, I will discuss how worked examples can improve transfer.

In CLT, the cognitive load imposed on working memory should be minimized when it is not related to schema construction and automation to enhance performance on transfer problems. To increase transfer, learners should be able to see identical elements between the training problems and the target problems irrespective of their surface features. Schemata constructed from the training problems help them to recognize these common elements and apply appropriate solution procedures. Also, learners need to be able to flexibly apply learned solution procedures and pay attention to unfamiliar aspects of the problems. Working memory plays a large roles in these abilities. Hence, building relevant schemata and having enough working memory capacity are important in transfer performance. In these respects, worked examples are recommended as effective instructional methods to improve far transfer. Worked examples not only promote schemata construction and automation but also reduce the problems' burden on working memory by providing worked-out solution steps and the final solution,

Research on worked examples has shown that they are effective for near transfer, but researchers have found inconsistent results for far transfer (e.g., Carroll, 1994; Cooper & Sweller, 1987; Hilbert & Renkl, 2009; Paas & van Merriënboer, 1994b; Salden, Aleven, Schwonke, & Renkl, 2010; Schwonke et al., 2009; Sweller & Cooper, 1985; Van Gog, Paas, & van Merriënboer, 2006, 2008). It is important to understand the effect of worked examples on far transfer because this is the type of transfer that students find most difficult; it is also most relevant to educators' concerns about how to help students apply what they learn in one setting to different contexts. Also, performance on far-transfer tests shows students' true understanding because students cannot mechanically apply what they memorized when they solve far-transfer tests. In this paper, I will review studies that explored the effectiveness of worked examples for increasing far-transfer performance.

CHAPTER 3

METHOD

I performed the literature search for the present review in January 2013. The following databases were searched: Social Sciences Citation Index (SSCI), Educational Resources Information Centre, and PsycINFO. Articles were included when they are (a) Social Sciences Citation Index listed; (b) written in English; (c) published between 1980 and 2012; (d) provided description of worked examples or Cognitive Load Theory in the theoretical, methodological, or results sections of the article; and (e) included far transfer as a variable of interest. “Worked examples,” “far transfer,” and “Cognitive Load Theory” were the main search terms. All articles that were found to include these terms in the title or in the abstract and meet the aforementioned criteria were selected and included in the review. I then conducted a hand-search through the reference sections of the articles I found, looking for other articles. I also used the Social Science Citation Index to find other articles that cited the ones I used, as a way to see if there were other articles. This research resulted in 27 articles that addressed far transfer as an outcome. I did not include articles that addressed near but not far transfer.

I searched journals like *Child Development, Cognitive Science, Cognition and Instruction, Computers in Human Behavior, Computers & Education, Contemporary Educational Psychology, Contemporary Educational Psychology and Metacognition and Learning, Developmental Psychology, Educational Psychology Review, Educational*

Psychologist, Instructional Science, Journal of Educational Psychology, journal of Experimental Psychology: Learning, Memory, and Cognition Learning and Instruction, Journal of the Learning Sciences, Learning and Instruction, Metacognition and Learning, Psychological Bulletin, Psychological Review, and *Review of Educational Research.* I found empirical articles dealing with the effect of worked examples on far-transfer performance (see Table1), but there were no reviews of these articles. Therefore, in this paper, I reviewed empirical articles focused on the effect of studying worked examples on far-transfer performance. The articles were analyzed and categorized according to their main research purposes. My review includes an overview of CLT, and what is currently known about the effects of worked examples for improving problem-solving skills in a near-transfer test, but my main contribution is a review of empirical articles regarding the effects of worked examples on far transfer.

CHAPTER 4

RESULTS

The research questions that I address in this section are:

- Does studying worked examples improve performance on far-transfer tests?
- What instructional strategies can be used to enhance the effect of studying worked examples on far transfer?
- Is studying worked examples an effective way of fostering transfer for some age groups as compared to others?

This result section starts with an introduction of a typical experimental design and two types of tests used to measure students' transfer performance in studies on worked examples. Next, studies on the effectiveness of worked examples for facilitating far transfer are reviewed. Furthermore, I explore which types of worked examples are better for transfer. To enhance the effectiveness of worked examples for far transfer, researchers have investigated the effectiveness of using a variety of instructional strategies such as self-explanation prompts, incomplete solution procedures, instructional explanations, or emphasizing subgoals. I review which formats lead to better outcomes for far transfer. Another thing that I explore is whether there are any interaction effects between age and worked examples.

Research Design and Transfer Tests

Typically, researchers studied the worked example effect by comparing performance of a worked-example group with that of a problem-solving group (e.g., Carroll, 1994; Cooper & Sweller, 1987; Hilbert & Renkl, 2009; Paas, 1992; Paas & van Merriënboer, 1994b; Rourke & Sweller, 2009; Salden et al., 2010; Sweller & Cooper, 1985). A typical worked-example experimental design is as follows: Students are randomly assigned to a worked-example group or a problem-solving group (i.e., true experimental design), and are then introduced to the target concept. After the initial introduction, students in the problem-solving group solve pairs of problems. Each pair presents a different problem type, but the two problems belonging to the same pair are structurally identical. Students in the worked-example group study the same pairs of problems, except that the first problem of each pair is worked out. This design, which compares example-problem pairs with problem-problem pairs, was first employed in Sweller and Cooper's study (1985) and has been used in many subsequent studies on worked examples (Sweller et al., 2011). The paired example-problem format was devised to prevent students from studying worked examples in a passive way during the learning phase.

Two different types of transfer tests have been used to measure learning outcomes. A near-transfer test consists of problems that have surface features and deep structure (i.e., solution procedures) similar to training problems. A far-transfer test consists of problems that have structural similarities with training problems but require the modification of the learned solution procedure to reach the solution. In some studies, different terms such as transfer tests (Cooper & Sweller, 1987) and dissimilar tests (Renkl, Atkinson, Maier, & Staley, 2002; Sweller& Cooper, 1985) were used to indicate a test requiring modifications of the learned solution procedure. Also, similar tests (Cooper & Sweller, 1987; Sweller & Cooper, 1985) or isomorphic tests (Gerjets, Scheiter, & Catrambone, 2006) were used to indicate the near-transfer test. Using these different types of transfer tests, researchers have examined the effectiveness of worked examples for enhancing near and far transfer. Among these studies, those focused on the far-transfer effect of worked examples are discussed in the following section.

Does Studying Worked Examples Improve Performance on Far-transfer Tests?

Studies in well-structured domains. Many researchers investigated the effects of studying worked examples on far transfer in well-structured domains such as mathematics, science, and technology (Rourke & Sweller, 2009). One of the earliest experiments was conducted by Sweller and Cooper (1985). They explored the effects of worked examples on the performance of high school students in algebra problem solving. In the experiment, participants proceeded through an initial introductory phase, a learning phase, and a posttest phase. During the introductory phase, the participants in both a worked-example group and a problem-solving group were introduced to the target problem-solving procedures with a few worked examples. After the introductory phase, the worked-example group studied example-problem pairs, while the problem-solving group solved the same problem pairs without worked-out solutions. Following the learning phase, students in both groups were asked to solve a set of tests which consisted of similar problems and dissimilar problems. The format of similar problems was identical to the format of the problems they studied during the learning phase. The dissimilar problems had different deep structure but required algebraic manipulations similar to what they had learned. The test scores of the two groups were compared to measure the near- and far-transfer effect of worked examples. The worked-example group achieved a higher score than the problem-solving group on the similar problems. However, there was no significant difference between the two groups on the dissimilar problems. In this experiment, the authors found the superiority of studying worked examples over solving problems for the similar problems, but they failed to find the positive effects of studying worked examples for dissimilar problems.

Cooper and Sweller (1987) argued that Sweller and Cooper (1985) might have failed to find the beneficial effects of worked examples on far transfer because little practice time was given compared with the number of target rules, so learners could not practice enough to automate solution procedures. They assumed that automation is necessary for far transfer and that for automation to occur more practice time should be given to learners. In a following experiment (Experiment 1), Cooper and Sweller (1987) hypothesized that increased practice would facilitate the far-transfer effect of worked examples through schema construction and automation. The authors used the same experimental design used by Sweller and Cooper (1985), except that they presented worked examples consisting of fewer algebra rules in order to increase learners' practice time. Participants were eighth graders from a Sydney high school. They studied algebra manipulation in either a worked-example group or a problem-solving group. In Experiment 1, Cooper and Sweller found no significant differences in the near-transfer performance of the two groups. However, the worked-example group achieved a significantly better performance compared with the problem-solving group on far-transfer problems.

Cooper and Sweller (1987) assumed the reduced number of algebraic rules might have caused the lack of positive effects of studying worked examples on near-transfer problems in Experiment 1. The reduced rules might have allowed both groups to build enough schemata necessary to solve similar problems. Thus, no significant differences were found on the similar problems between these two groups. They also suggested that the superiority of worked examples on far-transfer problems might have been found because only the worked example group was able to automate solution procedures. In a second experiment (Experiment 2), they investigated how the acquisition period (i.e., long and short) would affect near and far transfer. Also, the authors included students' abilities (i.e., high vs. low) as an independent variable to investigate the interaction effect between students' abilities and the two instructional methods. Learning outcomes were measured by similar problems (i.e., near transfer) and transfer problems (i.e., far transfer). The results of the similar problems showed that studying worked examples was more effective than problem solving for near transfer when participants' abilities were low, and the acquisition time was short. However, this beneficial effect of worked examples disappeared when participants' abilities were high, or when they were given long acquisition time. The performance on the transfer problems showed the opposite results. They could not find the superiority of studying worked examples for far transfer with low-ability and short-acquisition time groups. They only found it in the groups with either high ability or the long-acquisition period. However, for high-ability and long-acquisition groups, they did not find any beneficial effects of studying worked examples for far transfer. The results of this experiment suggest that studying worked examples may be more effective than problem solving for near and far transfer. However, this effect can be moderated by the learner's ability and the length of the acquisition period. No beneficial effects of worked examples were found in the performance of high-ability and long-acquisition period groups. Regarding far transfer, the results of this study indicate that it is important to give enough time to study worked examples to improve the far-transfer performance of low-ability students.

Paas (1992) also found evidence showing the effectiveness of worked examples for far transfer in an experiment comparing three conditions: worked examples, partially worked examples (i.e., completion problem condition), and problem solving. Paas hypothesized that studying worked examples or partially worked examples would result in better transfer performance and require lower mental effort compared with engaging in conventional problem solving. Participants who were second-year students of a secondary technical school studied how to measure different types of central tendency under one of the three conditions. The training problem sets consisted of three identical questions, but the format of the first two questions differed depending on each experimental condition. In addition to the questions, the worked-example condition group was given two worked-out examples, and the completion-problem condition group was presented with partially worked-out examples. The problem-solving condition group received only the questions. The participants in the completion-problem condition group were required to complete missing solution steps in worked examples. After the learning phase, they took a posttest that consisted of near-transfer problems and far-transfer problems. The far-transfer problems had different formats from the training problems, presented unstructured data, and required the application of different combinations of problem-solving strategies. The participants were also asked to rate their mental effort during the posttest phase to measure their cognitive load. As expected, the results of the experiment showed that studying worked examples and partially worked examples led to better far-transfer performance while investing less mental effort compared with problem solving. No significant differences were found between the two example formats. The results of this study suggest that studying worked examples may be more effective than solving problems in terms of far-transfer performance.

Paas and van Merriënboer (1994b) also showed that studying worked examples was more effective than problem solving for far transfer in geometry problem solving. They investigated the effectiveness of studying worked examples on the transfer performance of students aged 19 to 23 years in a secondary technical school in the Netherlands. The design of this study replicated previous studies (e.g., Cooper & Sweller, 1987; Paas, 1992) with a slight modification: Participants in the worked-example condition were required to study only worked examples without problem-solving demands. Participants in the problem-solving condition solved the same problems but without examples. In a posttest measuring far transfer of worked examples, it was found that the worked-example group yielded better far-transfer performance than did the problem-solving group.

Studies in ill-structured domains. Recently, more studies have been conducted in less structured learning domains (e.g., Hilbert & Renkl, 2009; Schworm & Renkl, 2007; Rourke & Sweller, 2009; van Gog et al., 2006). Researchers have examined whether worked examples are also effective in increasing problem-solving skills in tasks such as learning negotiation strategies (Gentner, Loewenstein, & Thompson, 2003), applying an instructional design model in creating learning tasks (Hoogveld, Paas, & Jochems, 2005), learning effective collaboration skills (Rummel & Spada, 2005; Rummel, Spada, & Hauser, 2006), learning troubleshooting skills (van Gog et al., 2006, 2008), learning argumentation skills (Schworm & Renkl, 2007), applying learning strategies in writing learning journals (Hübner, Nückles, & Renkl, 2010), using concept mapping as a learning strategy (Hilbert & Renkl, 2009), designing worked examples for instruction (Hilbert, Renkl, Schworm, Kessler, &

Reiss, 2008; Schworm & Renkl, 2006), proving in geometry (Hilbert, Renkl, Kessler, & Reiss, 2008), recognizing designers' styles (Rourke & Sweller, 2009), or learning to reason about legal cases (Nievelstein, van Gog, van Dijck, & Boshuizen, 2011). Some of these studies examined whether studying worked examples is more effective for increasing students' far-transfer performance compared with problem solving (e.g., Hilbert & Renkl, 2009; Rourke & Sweller, 2009; van Gog et al., 2006, 2008).

In a recent experiment, Rourke and Sweller (2009) examined whether studying worked examples could lead to better learning outcomes in identifying distinctive characteristics of designers' styles compared with solving equivalent problems. The authors randomly assigned first-year university students either to a problem-solving group or to a worked-example group. Students in the worked-example group were asked to identify the key characteristics of five chair designs and the designers of the chairs after studying five relevant worked examples. The problem-solving group solved equivalent problems without worked examples. After the learning period, two posttests were given to the participants to measure the near- and the far-transfer effects of the two instructional methods. In the near-transfer test, the students were given illustrations of ten chairs and required to match them to a list of designers that they had studied. In the far-transfer test, students were also required to identify the designer of a particular work with the key characteristics of their designs. In this test, the same designers' other works, such as a stained-glass window, a textile design, cutlery, and a silver tray, were used to measure far transfer. The results of the tests showed that the worked-example group outperformed the problem-solving group in both the near- and the far-transfer tests. The results of the tests provide evidence that the worked examples might be more effective for near and far transfer than problem solving, even for tasks from ill-defined domains.

Similarly to Rourke and Sweller (2009), Hilbert and Renkl (2009) also examined the effectiveness of worked examples in learning concept mapping as a strategy. Participants were students in a German Police Academy aged 18 to 30. An example group studied worked examples that explained how an advanced mapper constructed a concept map from given articles, and what cognitive processes occurred during this construction process. Participants in a practice group were asked to draw a concept map on their own from the same articles instead of studying examples. Students' learning outcomes were measured by two posttests. One posttest measured how effectively students could apply concept mapping skills to understanding an article. The other posttest measured student's conceptual knowledge about concept mapping. According to the authors, the former test required far transfer because it asked participants to apply concept mapping skills to a topic and a domain quite different from the original training domain. The authors also claimed that the conceptual-knowledge posttest also required far transfer because its questions were embedded in an application context. The authors found no beneficial effect of studying examples in both measures, and they suggested that this might be because students did not actively use their cognitive capacity reserved from studying examples. In the second experiment (Experiment 2), the authors included self-explanation prompts to encourage participants' active cognitive processes and tested whether the prompts made any significant differences on the effects of worked examples. This experiment will be discussed in a following section where I discuss the effects of employing self-explanation prompts on learning worked examples.

Van Gog et al. (2006) demonstrated that worked examples facilitated the development of problem-solving skills in the domain of electrical circuits troubleshooting, which indicates diagnosing and repairing faults in a technical system. First-year students in a senior secondary vocational school (age: *M*=17.40 years, *SD*=.90) studied faults in parallel circuits in a worked-example condition or a problem-solving condition. While the worked-example group was given worked-out solutions about how to repair the faults, the problem solving group only received acceptable goal states. After the learning phase, both groups were required to take a near and a far-transfer test. The near-transfer test had the same structural features and types of faults as those of the training tasks whereas the far-transfer test differed in both ways from the training tasks. The worked example group showed better performance than the problem solving group not only in the near-transfer test, but also in the far-transfer test. As with the previously discussed experiment (Rourke & Sweller, 2009), the results of this experiment indicate evidence that studying worked examples may be more effective than problem solving for enhancing far transfer, even for ill-structured domains.

Comparison with guided problem solving. Some researchers argued that former studies have found the superiority of worked examples because learning from worked examples was compared with unsupported problem solving (Koedinger & Aleven, 2007; McLaren, Lim, Gagnon, Yaron, & Koedinger, 2006). Some even claimed that the superiority of worked examples might not be found if worked examples were compared with supported problem solving (McLaren et al., 2006). Recently, more researchers have begun to compare studying worked examples with guided problem solving (Salden et al., 2010).

One of the earliest studies that compared worked examples with guided problem solving was conducted by Carroll (1994). Carroll explored the effectiveness of worked examples on far transfer by comparing the performance of students aged 15 to 17 in an example condition with the performance of their counterparts in a problem-solving condition. In this experiment, students learned how to translate English expressions into algebraic equations. A similar experimental design with previous worked-example studies was also used in this experiment. Students in the worked-example group studied worked examples followed by one similar practice problem, whereas students in the conventional problem-solving group solved only equivalent problems. However, unlike previous studies (e.g., Cooper & Sweller, 1987; Paas, 1992; Sweller & Cooper, 1985), where participants were not given any support while they engaged in problem solving, the problem-solving group in this study was supported by guidance from the instructor as needed during the learning period. Even though this extra support was available for the problem-solving group, the worked example group outperformed the problem-solving group in almost every measure including an in-class worksheet, a posttest, homework, and a delayed posttest. However, the worked-example group did not show better far-transfer performance, even though they spent less time and made fewer errors during the learning period. This study failed to demonstrate that worked examples are more effective than guided problem solving for far transfer.

Schwonke et al. (2009) also investigated the effectiveness of worked examples for enhancing far-transfer in the context of geometry problem solving supported by a computer-based cognitive tutor. The computer-based cognitive tutor provided guided learning by selecting appropriate problems according to students' progresses, giving feedback on their performance, and presenting hints when they struggled. In fading worked examples, after the initial presentation of a complete worked-out solution procedure, solution steps were gradually faded out at each task until the only problem is left. This fading strategy was devised to ensure learners' active processing of solution steps.

Schwonke et al. (2009) hypothesized that example-enriched tutored problem solving (i.e., worked-example condition) would lead to better learning outcomes than tutored problem solving (i.e., problem-solving condition) in algebra. In Experiment 1, high-school students in an experimental condition studied fading worked examples whereas students in a control condition solved problems in a tutored problem-solving environment. The authors looked for performance differences between these two conditions in a posttest comprised of four items measuring procedural transfer and nine items measuring conceptual transfer. Among the four procedural transfer questions, two of them measured far transfer. However, the authors combined the four item scores into an overall score because these items scores were highly correlated (r=.69; p<.001). The nine conceptual transfer items assessed far-transfer performance because the problems required explanation, argumentation and evaluation, all of which require the application of knowledge rather than simple calculation. Furthermore, the problems' surface features and mathematical structure were different from those of the questions that students encountered during the learning phase. The authors could not find significant differences between the two learning conditions in both procedural- and conceptual-transfer performance. However, after analyzing data, the authors suspected that students might have misunderstood the purpose of some procedures in worked examples, which might have affected the result of the experiment.

Schwonke et al. (2009) conducted another experiment (Experiment 2) in the same format as the first study, except that they inserted additional instructions to avoid the problems observed in Experiment 1. Ninth-grade and tenth-grade students in a German high school participated in the experiment. The authors found that studying fading worked-examples led to superior performance on a conceptual-transfer test. However, no significant differences were found in a procedural transfer test between the two learning conditions. Hence, the results of this study indicate that worked examples may be more effective than guided problem solving for conceptual far transfer but not for procedural transfer.

Salden et al. (2010) expanded the Schwonke et al.'s (2009) study by comparing three conditions in geometry problem solving: fading worked examples, adaptively fading-worked examples, and guided problem solving. In adaptively fading-worked examples, the rate at which the worked-out steps are faded is adapted to each individual student's progress. This study was conducted in the same format as the previous study (i.e., Schwonke et al., 2009). Participants were ninth and tenth graders in a German high school. Unlike the study by Schwonke et al, which detected the advantages of studying worked examples for conceptual far transfer, Salden et al. found no evidence favoring studying worked examples in tests measuring procedural or conceptual far transfer. However, the authors found that the adaptively fading group scored higher than the other groups in a long-term retention test.

According to CLT, worked examples enhance far transfer by minimizing extraneous load and simultaneously optimizing germane load. The studies discussed in this section investigated whether worked examples are effective instructional methods for increasing far transfer. The results of these studies have been inconsistent and the number of studies on this topic is limited. Some studies have found beneficial effects of studying worked examples on far transfer (e.g., Cooper & Sweller, 1987; Paas, 1992; Paas & van Merriënboer, 1994b; Rourke & Sweller, 2009; Schwonke et al, 2009; Van Gog et al., 2006) while others have not found any significant effects in terms of far-transfer performance (e.g., Carroll, 1994; Hilbert

& Renkl, 2009; Sweller & Cooper, 1985; Salen et al., 2010). Some researchers have suggested that the effectiveness of worked examples can be moderated by the length of acquisition time and learners' prior knowledge levels. Some researchers have also suggested that leaners' active processing of solution steps might play an important role in increasing the effectiveness of worked examples for far transfer. Some scholars have incorporated some instructional strategies such as self-explanation prompts, incomplete solution procedures, instructional explanations, or emphasizing subgoals into worked examples to increase their effectiveness in terms of far transfer. I will explore the results of studies on effectiveness of these instructional strategies in the next section.

What Instructional Strategies Can Be Used to Enhance the Effect of Studying Worked Examples on Far Transfer?

Understanding is important for far transfer (Mayer & Wittrock, 1996; Ohlsson & Rees, 1991). Far-transfer problems require the modification of solution steps as well as the flexible application of these steps, which is difficult without deep and principled understanding of solution procedures (Van Gog et al., 2004). This means that students should understand why and how these steps are taken and what rationales govern these steps in order to achieve better performance in far-transfer tests.

Some researchers have tried to find ways to encourage students' deep and active processing of worked examples. One line of research focused on encouraging students' active processing of worked examples by using partially worked-out examples or adding self-explanation prompts. Another line of research focused on deepening students' understanding by adding principled information to worked examples, for example, by providing instructional explanation or adding sub-goals. In this section, studies on the effectiveness of these strategies for facilitating learning from worked examples will be reviewed.

Completion worked examples. In an effort to encourage learners to process worked examples in an active way, an instructional method of leaving some key solution steps incomplete, which learners are requested to complete (i.e., completion worked examples), was devised. Sweller (1999) argued that including an element of problem solving would guarantee that learners attend to key information in depth. Solution steps can also be gradually faded out as learners' knowledge increases. This fading procedure initially presents learners with complete worked-out solution steps and systematically omits the solution steps one by one until only the problem statement is left. There are two types of fading procedures depending on a fading direction: a backward fading procedure and a forward fading procedure (Renkl et al., 2002). In the backward fading procedure, fading occurs in reverse from the last step. After a completely worked-out solution procedure is presented in the first task, the last solution step of the procedure is deleted in the second task; in the third task, the two last steps are omitted; and so on. The same fading process occurs in the forward fading procedure, but in the opposite direction. In the forward fading, the first solution step is faded out first, then the first and second steps, and so on

The effect of fading procedures on learning from worked examples can be understood in terms of the expertise reversal effect (Renkl, Atkinson, & Große, 2004). The expertise reversal effect refers to a phenomenon that information beneficial to learners with little domain knowledge becomes redundant or even interferes with learning when learners have advanced domain knowledge (Kalyuga, 2007). Kalyuga et al. (2001) found that studying worked examples became less effective as learners' expertise increased in the domain, and advanced knowledge learners benefited more from engaging in problem solving rather than studying worked examples. By presenting solution steps, worked examples helped the novices not to waste their working memory on solution searching (Kalyuga & Hanham, 2011). However, the additional instruction that worked examples provide might be already available in experts' long-term memory. In this case, working memory is used for processing redundant information, which does not result in schema construction. Because of the expertise reversal effect, it might be beneficial for learners, as learner's expertise increases, to increasing problem-solving demands gradually.

According to Renkl et al. (2002), fading procedures allow a smooth transition from studying completely worked examples to scaffolded problem solving and to independent problem solving. Also, they can improve learning from worked examples because fading enables learners to hold enough cognitive capacity to deal with problem solving demands and, at the same time, focus on understanding solution steps. Some researchers have explored whether leaving some solution steps incomplete could enhance performance on far transfer (e.g., Hilbert, Renkl, Kessler et al., 2008; Paas, 1992; van Merriënboer, 1990; van Merriënboer & de Crook, 1992).

Paas (1992) investigated the effectiveness of partially worked-out examples on increasing problem-solving skills for far-transfer tests. In this experiment, second-year students in a secondary technical school in Germany were given a lesson on statistics containing either incomplete examples (i.e., completion group), example-problem pairs (i.e., worked-example group), or only problems (i.e., problem-solving group). In a posttest measuring far-transfer performance, the worked-example group and the completion group outperformed the problem-solving group. The two worked-example groups did not show significant differences in their far-transfer performance. In case of a near-transfer test, the worked-example group showed better achievement than the other groups. This study demonstrated the positive effect of studying worked examples for near and far transfer as compared with problem solving, but it did not show benefits of leaving some steps incomplete in worked examples.

Renkl et al. (2002) also conducted an experiment (Experiment 1) to examine the effectiveness of fading worked examples for transfer performance in comparison to example-problem pairs in two ninth-grade classrooms from the German Hauptschule (i.e., the lowest track of the German three-track system). Participants received a physics lesson on electricity in two different conditions. One classroom was provided with backward fading examples. The other classroom was provided with example-problem pairs. Learning outcomes were assessed by a near- and a far-transfer test. While the near-transfer test had the same underlying structure as the problems students encountered during the learning phase, the far-transfer test had different underlying structure and surface features. The authors found the beneficial effects of the fading procedure on near transfer: The backward fading group achieved a higher score in the near-transfer test than the worked-example group. However, they could not find the advantages of the fading procedure on far transfer. This study demonstrated that a fading procedure can improve near transfer but not far transfer.

In a follow-up lab-based experiment (Experiment 2), Renkl et al. (2002) compared forward fading worked examples with traditional worked examples on near- and far-transfer performance. University students in the psychology department were provided with a lesson on probability in either a forward-fading condition or an example-problem condition. They got the same results with the Experiment 1: The forward-fading procedure enhanced near transfer, but did not make significant differences on far transfer. However, the authors found that the participants in the fading group produced fewer errors during the learning phase.

Renkl et al. (2002) conducted another experiment (Experiment 3) to compare a traditional example-problem condition to the two fading procedures. Students taking educational psychology courses were randomly assigned to a worked-example group, a backward-fading group, or a forward-fading group. The results of posttests indicate that backward fading was the most effective method for learning. In the posttests, both the forward-fading group and the backward-fading group outperformed the example-problem pair group. In case of dissimilar problems, the positive effect of fading was mainly seen in the performance of the backward-fading group. This result indicates that backward-fading worked examples might be the most effective instructional method for far transfer. When the performance of the two fading conditions was compared, there were no significant differences between them with respect to errors during learning and near-transfer performance. However, learners in the backward-fading group finished the training tasks more quickly. Also, they showed better far-transfer performance, but it was not statistically significant.

Atkison et al. (2003) also demonstrated the positive effect of fading procedures on far transfer. Participants who majored in educational psychology or psychology studied examples on probability calculation in either a backward-fading condition or an example-problem-pair condition. After the learning phase, the participants were required to take a near- and a far-transfer test. The far-transfer test consisted of problems that differed from the training problems in terms of structure and surface features. The authors found that the backward-fading group performed better than the example-problem group in both the near-and the far-transfer test. They concluded that the fading procedure enhanced near and far transfer.

Renkl et al. (2004) conducted an experiment (Experiment 1) to examine whether the position of the faded steps or the specific type of faded steps influences learning more. In this experiment, college students studied probability in one of four conditions that differed from each other in their fading direction (i.e., backward vs. forward) or in the principle that was faded (i.e., complementary rule vs. multiplication rule). They found that the position of faded steps affected learning less than their specific type. The authors suggested that faded steps might have increased the participants' self-explanation, which in turn improved their near- and far-transfer performance by deepening their understanding for solution steps. The results of this experiment shows that steps that are faded might affect students' performance regardless of their positions in worked examples.

Renkl et al. (2004) conducted another experiment (Experiment 2) to examine learning processes associated with a backward-fading procedure and example-problem pairs. In this experiment, US psychology students were randomly assigned to either a backward-fading condition or an example-problem-pair condition. The authors used the same experimental procedure and materials as the ones used by Renkl et al. (2002) in Experiment 2 and Experiment 3 except with one exception: They added think-aloud protocols (Ericsson & Simon, 1993) to investigate whether a fading procedure causes more self-explanation and what learning processes the two learning conditions trigger. The effects of the two conditions on learning were assessed by think-aloud data, a near-transfer test, and a far-transfer test. The far-transfer test had deep structure and surface features different from the training problems. Analyses of think-aloud data showed that the fading condition led to fewer unresolved impasses (VanLehn, 1998, 1999), which indicates that learners get stuck and perceive gaps in their understanding, compared with the example-problem condition. Also, the participants in the fading condition showed better near- and far-transfer performance than did the example-problem pair condition. The authors concluded that fading increased transfer performance by producing fewer unproductive learning events.

Reisslein, Atkinson, Seeling, and Reisslein (2006) compared a backward fading procedure with two example conditions (example-problem and problem-example). In this experiment, university students taking introductory engineering courses learned about series and parallel electrical circuit analysis in one of the three conditions. Students' prior knowledge (i.e., high versus low) was also included as an independent variable to investigate its interaction with the three learning conditions. Posttests measured near- and far-transfer performance. No significant differences in favor of worked examples were found among these three instructional conditions in the near-transfer tests or in the far-transfer tests. However, the authors found that low prior knowledge learners in the example-problem condition achieved a comparable level of performance with high prior knowledge learners. In the other conditions, high prior knowledge learners outperformed low prior knowledge learners. These results suggest that an example-problem pair condition might be more conducive for low prior knowledge learners.

Salden et al. (2010) examined the effectiveness of adaptive fading on learning from worked examples by comparing adaptively fading worked examples to fixed fading worked examples. High school students studied worked examples in the domain of geometry in either an adaptively fading condition or a fixed fading condition. The authors found the superiority of the adaptively fading condition over the fixed fading condition in both an immediate and a delayed far-transfer posttest.

Presenting partially worked examples has been investigated as an instructional strategy to encourage learners' active processing of worked examples. It is also assumed that a fading procedure makes it possible to gradually increase problem solving demands as learners' expertise increase in the target domain, which can result in increased performance on transfer tasks. In sum, previous studies on partially worked-out examples have shown that placing a gap in solution steps can lead to better performance on a near- and a far-transfer test. Some studies showed that a backward-fading procedure might be more effective than a forward-fading procedure for far transfer, but the results of experiments on this topic have shown inconsistent results. Finally, adaptively fading solution steps according to learners' progress was found to be a more effective procedure than a non-adaptive fading procedure.

Self-explanation prompts. Chi et al. (1989) argued that the extent to which learners benefit from studying worked examples depends on their individual effort to explain solution procedures to themselves. They called this phenomenon the self-explanation effect. According to Renkl (2005), self-explanation is especially important for improving far-transfer performance because it ensures that learners use their cognitive capacity reserved from studying worked examples for schema construction. Some studies have been carried out to investigate how self-explanation affects learning from worked examples.

Renkl, Stark, Gruber, and Mandl (1998) studied how the elicitation of self-explanation influences near and far transfer of worked examples. Participants, who were first- or second-year apprentices of a German bank, got a lesson on the calculation of compound interest and real interest using worked examples. They were randomly assigned to a spontaneous condition or an elicited self-explanation condition. The elicited self-explanation group received training on self-explanation and those participants were required to self-explain a solution procedure. Alternatively, the spontaneous group received training on a think-aloud procedure, and those participants were asked to verbalize their thoughts while they studied worked examples. After this initial training, all participants studied worked examples according to their own condition. Posttests measured the near- and far-transfer effects of these two different learning experiences. While near-transfer problems were structurally similar with the training worked examples, far-transfer problems had a different underlying structure. Performance on the far-transfer test indicated that the elicitation of self-explanation significantly enhanced far transfer of worked examples. The results of the near-transfer test also showed that self-explanation had beneficial effects on learning. However, these beneficial effects were mainly due to the performance of low prior-knowledge learners. They did not result in significant differences in the near-transfer performance of high prior-knowledge learners.

Atkison et al. (2003) conducted two experiments, one in a lab and the other in a school, to explore whether self-explanation prompts could enhance the effect of a fading procedure on far transfer. In the first experiment (Experiment 1), university students studied probability calculation in one of four conditions: (a) backward fading only, (b) example-problem pairs only, (c) backward fading with self-explanation prompts, and (d) example-problem pairs with self-explanation prompts. Self-explanation prompts asked the participants to examine each step and identify a principle used in each step. The participants in backward-fading conditions were asked to anticipate the answer for an omitted solution step. After they submitted their answer, the correct solution step was presented to them. After the learning phase, the participants took a near- and a far-transfer test. The groups provided with fading worked examples performed better than the other groups provided with example-problem pairs in near- and far-transfer tests. Also, the groups with self-explanation prompts outperformed the other groups without prompts. However, no interaction effects between the fading procedure and self-explanation prompts were found.

In Experiment 2, Atkison et al. (2003) investigated the effects of self-explanation prompts on a backward fading procedure in an authentic school setting. Students from a high school studied algebra problems with backward fading examples without self-explanation prompts or backward fading examples with self-explanation prompts. It was found that self-explanation prompts led to more accurate answers in near-transfer problems as well as far-transfer problems. This experiment demonstrated that self-explanation prompts can foster the effectiveness of fading worked examples not only for near transfer but also for far transfer.

A study by Schworm and Renkl (2006) indicated that learning from worked examples can be enhanced when worked examples are combined with self-explanation prompts. They used a 2 x 2 factorial design (i.e., with vs. without self-explanation prompts; with vs. without instructional explanations). In this study, student teachers and in-service teachers learned how to design effective worked-out examples in one of the four conditions. The instructional explanations were given as answers to the self-explanation prompts. Learning outcomes were measured by near- and far-transfer problems. The far-transfer problems belonged to a domain that was different from the original training domain. The group that was provided only with self-explanation prompts yielded better performance than the other groups on near- and far-transfer tests. The authors suggested that providing both instructional explanation and self-explanation prompts led to lower achievement than providing self-explanation prompts only, because the easy availability of a correct answer (i.e., instructional explanation) might have reduced learners' efforts to figure out the answer.

Hilbert and Renkl (2009) supposed that the reason they could not find any significant effect of worked examples for far transfer in their first experiment (Experiment 1) might be because the example group did not use freed cognitive capacity actively in building relevant schemata. The authors conducted another experiment (Experiment 2) to investigate whether adding self-explanation prompts could enhance learning on how to construct a concept map by encouraging learners to use freed cognitive capacity more actively. Participants who were 11th graders in a German commercial high school studied concept mapping in one of three different conditions: examples with self-explanation prompts, examples without self-explanation prompts, or practicing without examples. The results of posttests showed that the groups which studied worked examples had better conceptual knowledge about concept mapping than the practice group. When the worked example group with self-explanation prompts was compared with the worked-example group without self-explanation prompts, the former showed better performance in the application of concept mapping skills than the latter did. The authors concluded that even though studying examples is enough for enhancing conceptual knowledge about concept mapping, to improve the use of mapping skills in a real context, self-explanation prompts should also be added to worked examples.

Far transfer requires the application and modification of solution procedures, which is possible when learners have principled knowledge for solution procedures. However, learners tend to be passive and superficial in processing worked examples (Renkl, 1997). To promote learners' active principled-based self-explanations for solution steps, some researchers incorporated self-explanation prompts into worked examples (Atkinson et al., 2003). Research on self-explanation has demonstrated that presenting self-explanation prompts can be effective in increasing the far-transfer effects of worked examples: Some researchers have suggested that the effectiveness of self-explanation prompts might also depend on the level of each learner's prior knowledge and that there might be interactions effects between self-explanation and other types of strategies such as a fading procedure or instructional explanation.

Adding instructional explanation. Some studies have investigated the possibility of enhancing the transfer of worked examples by providing instructional explanation. According to Van Gog et al. (2004), worked examples are product oriented because they only show solution steps without explaining why these steps are taken and how to select appropriate steps. Van Gog et al. argued that adding strategic and principled information (i.e., process-oriented information) to worked examples, such as how and why those steps are taken, would enhance learners' understanding for solution procedures, thus enhancing far transfer.

Instructional explanation can also increase learners' understanding when it functions as feedback for students' performance. It can prevent students from reaching wrong conclusions by correcting their misunderstanding (Wittwer & Renkl, 2010). When students have gaps in their understanding, instructional explanation can fill in these gaps. In these ways, instructional explanations may increase students' understanding of worked examples, leading to better far-transfer performance. However, when instructional explanation is redundant, it can cause extraneous cognitive load. In this case, it may interfere with learning and lower transfer performance. Instructional explanation can also impede learning when it discourages learners' self-explanatory effort for justification of solution steps (Kulhavy, 1977).

Renkl (2002) examined whether adding instructional explanation to worked examples could increase the effectiveness of worked examples on the transfer performance of student teachers (M_{age}=23.3 years) in the domain of probability calculation. Participants in a control group studied worked examples without instructional explanation while participants in an experimental group studied worked examples with instructional explanation. In a posttest, the experimental group showed better performance than the control group. This positive effect of worked examples was mainly due to the far-transfer performance of the participants who studied worked examples with instructional explanation. Compared with their counterparts in the control group, they achieved higher scores on far-transfer problems. This study demonstrated that providing instructional explanation can enhance learning from worked examples for far transfer.

Schworm and Renkl (2006) also investigated how instructional explanation influences learning from worked examples. The results of posttests showed that instructional explanations improved learning from worked examples only when self-explanation prompts were not given. The participants who studied worked examples with instructional explanations and without self-explanations showed better performance than their counterparts who only studied worked examples. However, in the conditions with self-explanation prompts, learners showed better performance when they were not given instructional explanations. The group which was presented with only self-explanation prompts outperformed the other groups. This experiment demonstrated that providing instructional explanation can enhance learning from worked examples, but not as much as providing self-explanation prompts.

In a follow-up study, Hilbert, Schworm, and Renkl (2004) investigated how to optimize the combination of instructional explanation and self-explanation prompts. They used the same learning environment as in the previous study (i.e., Schworm & Renkl, 2006), but they changed the presentation of instructional-explanation prompts and self-explanation prompts. To prevent learners from relying on instructional explanations while self-explaining solution steps, instructional explanations were given before self-explanation prompts. Studying worked examples with instructional explanation and self-explanation prompts was compared with studying worked examples with only self-explanation prompts. The authors could not find significant differences between these two learning conditions in students' performance. Providing instructional explanation did not make any significant differences in learning from worked examples.

Gerjets et al. (2006) examined whether adding instructional explanations to worked examples could improve transfer performance by helping learners to elaborate on worked examples. University students learned how to calculate probability in three conditions that differed from each other in the level of elaboration of instructional explanation. A high-level condition was composed of highly elaborated instructional explanations, such as justifications for a choice for a solution step. A medium-level instructional-explanation group was presented with facts regarding solution steps such as individual event probabilities without further justifications. A low-level group was not given any verbal explanations. When the authors compared the performance of these three groups on isomorphic problems and novel problems, they found no beneficial effects of adding instructional explanation to worked examples.

Van Gog et al. (2006) hypothesized that adding process-oriented information, such as how and why steps were taken, would enhance the effectiveness of worked examples for transfer performance. They further hypothesized that combining process-oriented information with problem solving would decrease its effectiveness by imposing extra cognitive load on learners who might already have high cognitive load caused by problem solving activities. In this experiment, first year elecrotechnics students from three secondary schools studied training tasks in four different learning conditions: conventional problem solving with process-oriented information, conventional problem solving without process-oriented information, and worked examples with process-oriented information, worked examples without process-oriented information. The authors did not find significant effects of providing process-oriented information on students' performance. The groups provided with process-oriented information did not show better or worse performance on the near or far-transfer tasks compared with the groups not provided with process-oriented information. Also, no significant interaction effects between process-oriented information and worked examples or problem solving were found for near- and far-transfer performance.

Van Gog, Paas, and van Merriënboer (2008) assumed that the lack of a positive effect of process-oriented information in the previous study (Van Gog et al., 2006) might have been due to the expertise reversal effect. The authors supposed that learners' expertise might have increased during the learning phase, so process-oriented information might have become redundant and interfered with learning by taking up working memory space without further contributing to schema construction. They conducted another experiment to examine this supposition. In this experiment, the authors hypothesized that presenting process-oriented information would initially enhance learning from worked examples when learners' expertise was low. They further hypothesized that removing process-oriented information after learners reach a certain level of understanding would lead to better transfer performance than continuously presenting it. To test this hypothesis, they used a repeated measures design, which consisted of two training sessions each followed by a transfer test. During the first training section, participants, who were fifth-year secondary education students (M_{age} = 16.10 years), were required to study worked examples on trouble shooting with process-oriented information (i.e., process condition) or without process-oriented information (i.e., product condition). After the first session, both groups took the first test measuring near and far transfer. During the second training session, the participants in each group were again randomly assigned to either a process condition or a product condition. This means that the participants studied worked examples in one of four conditions: process-process, process-product, product -process, and product - product. The second learning session was also followed by a second transfer test. The authors used training tasks, a mental effort measure, and near and far-transfer tests similar to the ones used in the previous study (i.e., Van Gog et al., 2006). Standardized performance scores and mental effort scores were used to calculate the efficiency of each condition.

As Van Gog et al. (2008) had expected, the results of the first test showed that students who studied worked examples with process-oriented information obtained a higher efficiency score than their counterparts without process-oriented information. This is because the process group exerted less mental effort compared with the product group while achieving a similar performance level. In the second transfer test, the process-product group showed a higher efficiency when compared with the process-process group. However, the efficiency score of the process-product group was not higher than that of the product-product and the product-process group. The authors explained that this might be because the product-product and the product-process condition also contributed to building schemata of enough quality for students in these three conditions to show equivalent performance levels. They also supposed that if the students in the process-product group had self-explained the rationale governing solution steps while they studied worked examples without process-oriented information, then they might have shown better transfer performance.

Instructional explanations can enhance learning from worked examples by increasing students' understandings for solution steps. Studies on instructional explanation showed inconsistent results for the benefits of instructional explanation on learning from worked examples. Some researchers found the positive effects of instructional explanation on studying worked examples (e.g., Renkl, 2002; Schworm & Renkl, 2006). Others did not find any evidence favoring adding instructional explanation to worked examples (e.g., Gerjets et al., 2006; Hilbert et al., 2004; Van Gog et al., 2006). Some researchers suggested that other factors, such as learners' expertise levels or interactions with other strategies, might moderate the effectiveness of instructional explanation on learning from worked examples (e.g., Schworm & Renkl, 2006; Van Gog et al., 2008). In general, the number of studies that explored the effects of instructional explanation on far transfer is low. Further research on these factors might lead to a more conclusive conclusion on the effectiveness of instructional explanation on studying worked examples.

Adding subgoals. According to Catrambone (1995), subgoals can enhance learners' transfers to a novel problem because subgoals group a set of solution steps and explain what these steps try to achieve. Also, subgoals help learners to recognize which solution steps need modifications in order to apply them to a new problem. Catrambone conducted a series of studies (1994a; 1994b, 1995, 1996, 1998; Catrambone & Holyoak, 1990) to examine whether formatting worked examples in a way that emphasizes the subgoals of solution procedures could improve transfer to a novel problem. These studies have shown that highlighting subgoals increases the effect of studying examples for far transfer. Students who studied worked examples with emphasized subgoals outperformed their counterparts who studied worked examples without this emphasis.

Catrambone and Holyoak (1990) explored the effect of emphasizing subgoals of solution procedures using annotations in probability calculation. University students in the experimental group studied worked examples with highlighted subgoals. Students in the control group studied worked examples without salient subgoals. There were no significant differences in learning outcomes between the two groups on similar problems. However, students who studied worked examples with highlighted subgoals showed better performance than their counterparts in the non-highlighted subgoal group on transfer problems that required modifications of solution procedures. The authors concluded that using annotations to emphasize subgoals of solution procedures can facilitate far-transfer performance by helping learners to recognize which solution steps need modifications to get solutions.

In subsequent studies, Catrambone (1994a; 1994b, 1995, 1996, 1998) investigated the efficiency of labeling and visual isolation of solution steps as a technique for highlighting subgoals. Catrambone found that labeling and visual isolation of solution steps also facilitated the learning of the subgoals of solution procedures, which in turn enhanced the far transfer of solution procedures to a novel problem. His studies provided evidence showing that emphasizing subgoals could enhance far transfer of worked examples.

In this section, I investigated the effects of incorporating instructional strategies into worked examples. Some studies examined whether instructional strategies, such as presenting partially worked-out examples or self-explanation prompts, that encourage active processing of worked examples, could enhance the far-transfer effects of worked examples. Other studies explored whether adding principled information, such as process-oriented information or subgoals, could enhance learning from worked examples. From the results of these studies, I found that most of these strategies are effective for increasing transfer except instructional explanations. The effectiveness of worked examples for far transfer remains inconclusive. Some studies found beneficial effects of adding instructional explanations to worked examples. However, others did not find any statistically significant effects in terms of far transfer. In the next section, I will review research that explored differences in the effectiveness of worked examples among different age groups.

Is studying worked examples a more effective way of fostering transfer for certain age groups as compared to others?

Regarding differences in the effectiveness of worked examples among age groups, I found one empirical study (i.e., Van Gerven, Paas, Van Merriënboer, and Schmidt, 2002). Van Gerven et al. expected that studying worked examples would bring more benefits to the elderly than the young. That is, they assumed that worked examples would induce less cognitive load in the elderly while allowing them to obtain an equal level of near- and far-transfer performance in less time. In this experiment, a younger group consisted of university students, while an elderly group consisted of people who were between 61 and 76 years of age. Each group studied given tasks in either a worked-example condition or a problem-solving condition. The participants were given water-jug problems, which asked participants to acquire a certain amount of water by using jugs of different size containing different amounts of water, were used for a learning domain. To measure the efficiency of the two instructional methods, the authors required the participants to rate their cognitive load during the learning phase. Also, the authors recorded the amount of time subjects spent on solving training problems. After studying in different conditions, the participants took a near- and a far-transfer test. The results of the experiment showed that worked examples were more beneficial to the elderly than to the younger group. The elderly invested less mental effort when studying worked examples while achieving an equal performance level. This interaction effect was stronger in far-transfer tests than in near-transfer tests. This experiment suggests that the elderly might gain more benefits from studying worked examples than the young.

Few researchers examined the effect of worked examples for the elderly. Participants in most experiments on worked examples were high-school students or university students (see Table 1). This is why questions such as whether studying worked examples is also beneficial to preschoolers or elementary school students, remains open ones.

In this review, I investigated (1) whether studying worked examples improve performance on far-transfer tests; (2) what instructional strategies can be used to enhance the effect of studying worked examples on far transfer, and (3) whether studying worked examples is a more effective way of fostering transfer for certain age groups as compared to others. The previous studies have shown inconsistent results on the effectiveness of worked examples for far transfer. However, in general, more studies indicate evidence that studying worked examples can enhance performance on far-transfer tests. In terms of employing instructional strategies, the presented findings suggest that presenting partially worked-out solution steps, subgoals, and self-explanation prompts might facilitate learning from worked examples for far transfer. However, whether learning from worked examples can be supported by instructional explanation is inconclusive. Also, studying worked examples seems to be more beneficial for older age groups than younger age groups.

CHAPTER 5

CONCLUSION

Previous studies have examined the effectiveness of worked examples for far transfer in comparison to problem solving in well-structured domains as well as ill-structured domains. Some of them compared the effect of worked examples to guided problem solving. In general, more studies have shown that learners achieved better performance for similar and dissimilar problems after they studied worked examples than when they engaged in problem solving. According to CLT, worked examples are effective instructional methods for enhancing transfer because they enable leaners to devote their limited working memory to building relevant schemata and automating them by presenting the solution steps and the final solution.

CLT views that schema construction and automation play an important role in increasing learners' performance on transfer problems (Paas et al., 2003). Transfer problems are likely to have a number of unfamiliar interacting elements, and learners need to simultaneously process these novel interacting elements to reach the solution. However, working memory can process only a few elements at the same time because of its limited capacity. Thus, transfer problems are likely to impose cognitive load that exceed the capacity of working memory, lowering learners' performance. Schemata help learners to bypass the limitations of working memory and improve their problem solving skills for transfer tasks.

Schemata activated from long-term memory can improve transfer by expanding working memory capacity (Anderson, 2000). Schemata, as hierarchical knowledge structures, combine individual elements into a single common set of elements. This means that only one element is processed when actually many incorporated elements are processed in working memory. Thus, when there are relevant schemata in long-term memory, working memory can process more information than it can when working with individual elements. Also, automatically processing these elements can further increase transfer performance because more working memory capacity is available to deal with unfamiliar aspects of the problems. Thus, CLT suggests that limited working memory should be devoted to schemata construction and automation to increase performance on transfer tasks, and cognitive load induced by other activities not related to schema construction and automation should be minimized. Worked examples prevent learners from wasting their working memory capacity on activities not related to schema construction and automation, such as a mean-ends analysis strategy, by presenting solution procedures and the final solution. Hence, studying worked examples are an effective way of increasing transfer.

Generally, more studies showed the worked example effect. However, some studies failed to find any superiority of studying worked examples over problem solving (e.g., Carroll, 1994; Hilbert & Renkl, 2009; Sweller & Cooper, 198 5; Salen et al., 2010). These inconsistent findings may have resulted from the students' lack of conceptual knowledge (Van Gog et al., 2004) and conditional knowledge. To show better performance on problems that require application of learned solution steps, learners need to know why these steps are taken, what principles are applied to draw these steps, and when these steps can be applied; they need to have conceptual and conditional knowledge for the solution steps. When they mechanically apply the solution steps without principled understanding, they are more likely to have only procedural knowledge, and it might decrease their performance on transfer problems.

Some researchers have investigated how to improve learning from worked examples for far-transfer performance. One line of research has suggested presenting principled information to students by adding an instructional explanation or subgoals to worked examples. Another line of research suggested using strategies that can encourage students' active processing for solution steps such as leaving some solution steps incomplete, gradually fading solution steps, or adding self-explanation prompts. These instructional strategies might enhance transfer of solution steps by helping students acquire conceptual knowledge for solution procedures. They might increase germane load because they contribute to schema construction and automation by encouraging active processing of solution steps and by deepening learners' understanding for solution procedures. Most of these strategies have been found to be effective for improving learning from worked examples except adding instructional explanations. Research on the effect of instructional explanations has shown inconsistent results: Some studies found the advantages of adding instructional explanations to worked examples while others did not find any significant differences compared to studying worked examples. This might be because these studies did not take into account students' knowledge levels and their interaction with other instructional strategies (Schworm & Renkl, 2006; Van Gog et al., 2008).

Kalyuga et al. (2003) suggested there might be interaction effects between instructional methods and the levels of learners' prior knowledge level. Experts have schemata that can guide them in information processing and solution search. When instruction focuses on promoting the construction of schemata, experts get redundant information from two different sources, one from instruction and the other from their schemata. In most cases, they try to compare, relate, and integrate redundant components. This process can impose additional cognitive load and overload working memory. Therefore, for experts, it might be better to remove instructional guidance (e.g., worked examples). Instructional methods that encourage them to use their own schemata might be more effective and beneficial for transfer (e.g., problem solving).

A few studies explored whether there were any interaction effects between different instructional strategies (e.g., Atkinson et al., 2003; Schworm & Renkl, 2006). Schworm and Renkl (2006) found that the effectiveness of self-explanation prompts for far transfer may be reduced when they are combined with instructional explanations. Some studies suggested that learners' expertise levels might moderate the effectiveness of instructional strategies for far transfer (e.g., Reisslein et al., 2006; van Gog, 2008). Further consideration of interaction effects among these variables might lead to more consistent results. In sum, results of this review suggest that worked examples can be used to increase far transfer of problem-solving skills when they are combined with instructional strategies such as self-explanation prompts, incomplete solution procedures, or adding subgoals.

Implications for Educators

My review suggests that teachers can use worked examples to increase students' problem-solving skills on far-transfer tasks. To enhance their effectiveness on far transfer, those worked examples should be supported by self-explanation prompts, incomplete solution procedures, or subgoals. These instructional strategies can promote students' active processing of solution steps. They can also help students have conceptual and principled understanding of the solutions steps. However, teachers should consider students' knowledge levels when they employ worked examples because its effectiveness on increasing problem-solving skills for far-transfer tasks might be moderated by the levels of learners' prior knowledge. High prior knowledge learners might benefit more from problem solving than worked examples.

Limitations

My review on the effectiveness of worked examples based on CLT has several limitations. First, even though there are numerous studies on the effect of worked examples, few of them have investigated how studying worked examples affects far-transfer performance. The number of empirical studies is limited, so it is difficult to draw a conclusive conclusion on this topic. Also, it is hard to generalize the findings from the studies in this review to age groups other than adolescents or young adults. This is because participants were high school or university students in most studies, which makes it difficult to draw definite conclusions about whether the worked example effect is also applicable to other age groups such as children or the elderly. Moreover, few studies explored the long-term effect of studying worked examples. Posttests in most studies were implemented right after the learning phase, so the results of these posttests only show the short-term effects of studying worked examples on far-transfer performance.

Also, my review does not elucidate how learners encode worked examples, construct schemata, and retrieve them for problem solving. . CLT focuses on reducing extraneous load on working memory in order to make information processing more efficient for schema construction and automation. This is why studies on worked examples have also tended to focus on whether worked examples could contribute to schema construction and automation by reducing load on working memory and do not provide detailed illustrations of what cognitive process occurs when schemata are constructed from worked examples.

Future Directions

This review of previous research focused on the effect of worked examples on far transfer and presents some suggestions for future research. First, future studies might document the effectiveness of studying worked examples for far transfer under particular circumstances: Which type of instruction is effective for learners at which knowledge level? Previous studies have shown that there might be interaction effects between learners' knowledge levels and instructional strategies; however, few studies have investigated this interaction with instructional strategies. Also, future studies might investigate interactions between instructional strategies: Does presenting fading worked examples with self-explanation promote learning from worked examples by encouraging active processing, or hinder learning by imposing excessive amounts of load on working memory? What are the effects of presenting instructional explanation in terms of learners' self-explanation? Does instructional explanation discourage learners' self-explanation efforts or does it fill gaps in learners' self-explanation? How can these instructional strategies be combined to optimize their effectiveness?

Also, further research on the effects of studying worked examples on far transfer for different age groups might provide valuable insights on how cognitive development affects learning from worked examples. Because elementary school students' working memory has not been fully developed, they have more limited working memory capacity compared to adults. If studying worked examples is really beneficial for bypassing the limitations of working memory, they would be more beneficial for elementary school students than adults.

However, there were few studies that examined the worked example effect with elementary school students. In the future, researchers should study the effects of worked examples on far transfer with elementary school students.

Also, future research needs to address the long-term effects of studying worked examples by giving learners more time to internalize worked examples. In most studies, participants were given limited time to study training tasks during the learning phase. Given the nature of heuristic learning, increasing learning time might produce a different learning outcome, so future studies also need to consider how the prolonged learning phase affects far-transfer performance.

Table 1

Summary of Experimental Studies

Study (Year)	Description	Learning Domain	Learning Measure	Participants
Sweller & Cooper (1985, Experiment 4)	Effects of worked examples on similar and dissimilar tests in comparison to problem solving	Mathematics	Near transfer, far transfer	Year 8 Sydney high school
Cooper & Sweller (1987)	Relations between schema acquisition and rule automation on learning and transfer	Mathematics	Near transfer, far transfer	Eighth-grade Sydney high school students
Catrambone & Holoyoak (1990)	Effectiveness of subgoals for enhancing learning from worked examples	Mathematics	Near transfer, far transfer	University students
Paas (1992)	Comparison of problem solving, worked examples, and partially worked-out examples for near and far transfer	Statistics	Near transfer, far transfer	2nd-year secondary technical school students (aged 16-18)
Paas & Van Merrienboer (1994)	A low- and a high-variability problem-solving condition compared with a low- and a high-variability worked example condition	Mathematics	Near transfer, far transfer	4th-year secondary technical school students (aged 19-23)
Carroll (1994)	Worked examples for translating English expressions into algebraic equations	Mathematics	Near transfer, far transfer	High school students (aged 15-17)
Catrambone (1994)	Effect of labeling solution steps on transfer	Mathematics	Near transfer, far transfer	University students
Catrambone (1994)	Effect of emphasizing of a subgoal on transfer	Mathematics	Near transfer, far transfer	University students
Catrambone (1995)	Effect of labeling and visually isolating a set of steps on transfer	Mathematics	Near transfer, far transfer	University students
Catrambone (1996)	Effect of grouping steps from examples on learning subgoal and transfer problems	Mathematics	Near transfer, far transfer	University students
Renkl, Stark, Grube, & Mandl (1998)	Extent that example variability and elicitation of sophisticated self-explanations foster acquisition of transferable knowledge by learning from worked-out examples	Mathematics	Near transfer, far transfer	1st- and 2nd-year apprentices in bank training department

Van Gerven, Paas, Merriënboer, & Schmidt (2002)	Effect of studying worked examples on transfer tests	Water-jug problem	Near transfer, far transfer	University psychology students (aged 18-30; M = 19.50) elderly (aged 61-76; M = 66)
Renkl (2002)	Effect of adding instructional explanation	Mathematics	Near transfer, far transfer	University students
Renkl, Atkinson, Maier, & Staley (2002)	Effect of fading worked example procedures on transfer tests in comparison to example-problem pairs	Mathematics	Near transfer, far transfer	9th-grade German secondary school students, American psychology university students
Atkison, Renkl, & Merrill (2003)	Effectiveness of fading procedures on far transfer	Mathematics	Near transfer, far transfer	Educational psychology & psychology university students
Renkl, Atkinson, & Große (2004)	Learning processes and mechanisms that occur in computer-based learning environment containing faded worked solution steps	Mathematics	Near transfer, far transfer	American psychology students; university students
Hilbert, Schworm, & Renkl (2004)	Find a favorable combination of instructional explanations and self-explanation prompts in studying worked examples	Instructional design	Near transfer, far transfer	Education students from 2 universities (M = 22.2)
Gerjets, Scheiter, & Catrambone (2006)	Effect of instructional explanations and prompting self-explanations on molar and modular worked examples be enhanced by providing	Mathematics	Near transfer, far transfer	University students (M = 24.64, SD = 6.280)
Reisslein, Atkinson, Sseling & Reisslein (2006)	Effect of example-problem, problem-example, and fading on electrical circuit analysis	Physics	Near transfer, far transfer	University students in intro engineering at Arizona State University
Schworm & Renkl (2006)	Whether effects of self-explanation prompts on instructional explanations can be generalized to solved example problems	Instructional design	Near transfer, far transfer	University students (M = 22.3)
Van Gog, Paas, & Merriënboer (2006)	Effect of process-oriented worked examples on troubleshooting transfer performance	Physics	Near transfer, far transfer	1st-year electrotechnics students in school of senior secondary vocational education (M = 17.40, SD = 0.90)
Van Gog, Paas, & Merriënboer (2008)	Effect of studying sequences of process-oriented and product-oriented worked examples on troubleshooting transfer efficiency	Physics	Near transfer, far transfer	5th-year secondary education students (highest level of secondary education; M = 16.10, SD = 0.49)

Hilbert & Renkl (2009)	Use of examples for acquiring a computer-based concept mapping	Concept Mapping	Conceptual knowledge	German Police Academy cadets (aged 18 to 30; *M* = 22.53, *SD* = 3.43)
Rourke & Sweller (2009)	Effect of studying worked-example compared with problem solving in ill-defined problems	Recognizing designers' styles	Near transfer, far transfer	1st-year-university students
Schwonke, Renkl, Krieg, Wittwer, Aleven, & Salden (2009)	Comparing tutored problem solving to worked examples on procedural and conceptual transfer tests	Mathematics	Procedural transfer, conceptual transfer	8th & 9th grade students
Salden, Aleven, Schwonke, & Renkl (2010)	Adaptively fading worked examples in a tutored problem-solving environment might lead to higher learning gains	Mathematics	Procedural and conceptual transfer	9th &10th grade American high school students (*M* age = 15.63, *SD* = 0.84)

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