INSTRUCTION BASED ON EXAMPLES

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The path of precept is long, that of example short and effectual.

(Seneca, about 4 BC to 65 AD)

INTRODUCTION

Often in schools, at university, or in further education, abstract concepts and principles are taught without giving students the opportunity to work on how this abstract knowledge can be applied. For example, principles of scientific argumentation are explained in university lectures without enabling students to learn how to apply them. Mere inert knowledge (Whitehead, 1929) is often acquired in such situations. Learners can state the relevant concepts and principles, but they cannot (or at least do not) apply them when solving complex problems.

In other cases, such as project-based learning, learners may encode concrete problem solutions. However, this is often of little help when solving subsequent related problems. Such deficient knowledge use is mainly due to two factors. For one, learners may not have encoded the general rules or principles behind the previously encountered problem solutions. For another, the learners may not have noticed the relevance of the known problem solutions (e.g., Renkl, 2014).

To enhance cognitive skills, instruction should encourage learners to encode and interconnect both abstract concepts and principles, on the one hand, and concrete cases in which this abstract knowledge is applied, on the other hand. In order to get to such interconnected knowledge structures, instruction by examples, especially as specified in research on worked examples, is an appropriate instructional method (Renkl, 2014).

Figure 15.1 illustrates an example in a double sense. It is taken from an example-based learning environment by Hilbert, Renkl, Schworm, Kessler, and Reiss (2008) in which teachers learn how to design worked examples for high-school students. In this environment, it is argued that in the beginning, computationally efficient but difficult to understand formulas (left side of Figure 15.1) should be avoided (the general rule). Instead, the design should use easy-to-understand solution procedures (right side of
Figure 15.1). The teachers learned about the principles of example design (i.e., the general rule) and were shown two concrete examples, one in accordance with and one opposing this rule. In addition, they were requested to explain why the given examples were in accordance with or contrary to the rule. By explaining the “why?” (see Figure 15.1), teachers should connect the general rule with the concrete examples, which should lead to an integrated representation. To fully exploit the potential of example-based instruction, explanations must be elicited from learners. As the learners provide such explanations by themselves and primarily for themselves, such explanations are called self-explanations (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997; also see Chapter 16 in this volume).

Proponents of teaching and learning by examples propose that after the explicit introduction of one or more domain principles (e.g., mathematical theorem, physics law, or design principles for worked examples), learners should be presented with several examples rather than just one, as is usually the case. The basic argument is that learners should first gain understanding of the abstract principles and their application in problem solving before solving problems on their own. Otherwise they engage—due to their lack of understanding—in superficial strategies that do not deepen understanding (e.g., Renkl, 2014). Despite this emphasis on examples, these proponents also acknowledge the importance of solving problems later on in cognitive skill acquisition to reach proficiency (e.g., Kalyuga, Ayres, Chandler, & Sweller, 2003; Renkl, 2014; Renkl & Atkinson, 2003).

Research on worked examples initially focused on well-structured domains such as mathematics and physics. In the meantime, research has also analyzed learning from more ill-structured domains such as identifying designer styles (Rourke & Sweller, 2009), collaborating productively (Rummel, Spada, & Hauser, 2009), engaging
in scientific argumentation (Schworm & Renkl, 2007), applying learning strategies in journal writing (Hübner, Nückles, & Renkl, 2010), or reasoning about legal cases (Nievelstein, van Gog, van Dijck, & Boshuizen, 2013). In these cases, the examples were not necessarily presented in printed form, like typical worked examples from mathematics or physics. In part, video models were used (e.g., Rummel et al., 2009; Schworm & Renkl, 2007). This development has blurred the boundaries between traditional example research and observational learning research in the tradition of Bandura’s (1986) socio-cognitive learning theory. Hence, I also include research on observational learning in this chapter.

Example-based instruction, especially when combined with self-explanation elicitation, has the advantage of interrelating principles and instances when initial cognitive skills are being acquired. However, does it really lead to superior skill acquisition? The answer is a clear “yes.” There are numerous studies revealing the superiority of example-based learning to problem solving in initial cognitive skill acquisition (e.g., Carroll, 1994; Cooper & Sweller, 1987; Eysink, de Jong, Berthold, Koloffel, Opfermann, & Wouters, 2009; Hilbert, Renkl, Kessler, & Reiss, 2008; Sweller & Cooper, 1985; Paas & van Merriënboer, 1994; Zhu & Simon, 1987; see also Hattie, 2009). Learning by examples is even superior when learning by problem solving is well-supported (Salden, Aleven, Renkl, & Schwonke, 2010; Schwonke, Renkl, Krieg, Wittwer, Aleven, & Salden, 2009).

Given the effectiveness of example-based instruction, it is worth considering this method in detail. In the following, an historical sketch of the roots of instruction by examples is provided. Second, important theoretical foundations of this approach are discussed. Third, evidence-based principles for instructional design are presented. Finally, recent developments in research on worked examples, as well as fruitful lines of further research, are outlined.

HISTORICAL SKETCH

Seneca’s quote that opens this chapter is evidence that the appreciation of examples as a means of learning and teaching has a very long tradition. This section, however, adopts a more short-term perspective in which four important roots of research on example-based instruction are considered: research on concept formation, social-cognitive theory, analogical reasoning, and cognitive load theory.

Research on Concept Formation

From the mid-1950s on, psychologists examined how concepts are formed by the provision of examples (e.g., Bruner, Goodnow, & Austin, 1956; Tennyson & Cocchiarella, 1986). Merrill and Tennyson (1977) formulated a concept-teaching model containing four main elements: (a) provision of a verbal rule; (b) expository instances (i.e., examples and non-examples of a concept); (c) interrogatory examples, meaning that the learners have to answer questions on critical attributes of instances to determine whether it is an example or a non-example of a category; and (d) attribute elaboration (i.e., learners reflect on the critical attributes of examples). It is not too difficult to map these instructional design elements to the features of the “modern” worked examples approach shown in Figure 15.1: introduction of a principle (a), provision of a series of examples (b and c), and self-explaining these examples (c and d).
Research on Social-Cognitive Theory

Bandura (1971) made the following statement in the introduction to his book *Psychological Modeling*: “This volume is principally concerned with learning by example” (p. 1). In accord with research on worked examples, Bandura (1986) advocated using multiple examples or models (e.g., Bandura, 1986). He emphasized that models are examples instantiating rules, especially in, what he calls, “abstract modeling.” Such modeling refers to the acquisition of cognitive skills based on underlying abstract rules or principles (in contrast to models that can be more or less mimicked, e.g., motor skills). Bandura’s approach has led to social-cognitive research programs on teaching academic skills such as reading and writing by modeling (e.g., Schunk & Zimmerman, 2007).

Research on Analogical Reasoning

Analogical reasoning began to be researched intensively in the 1980s (e.g., Gick & Holyoak, 1983). In this research tradition, four phases are usually distinguished (Holyoak, 2005; Reeves & Weissberg, 1993). First, examples are encoded and presented as sources of transfer or further learning, and a pertinent schema is potentially constructed in the process (phase 1). When a transfer problem is to be solved, potentially relevant analogs are activated and selected (phase 2). The problem to be solved is mapped onto the analog (phase 3)—that is, the learners determine the communalities and differences between a known problem (analog) and the new problem at hand. Finally, the induction of an abstract schema might arise out of this mapping process (or the modification of a schema already constructed in phase 1), because the learners notice that some superficial features (e.g., concrete numbers and objects in a mathematics word problem) are not relevant to the appropriate solution method. The relevant structural features are thus encoded as a schema (phase 4). Analogical reasoning research has also led to instructional approaches. For example, Gentner and colleagues (e.g., Gentner, Loewenstein, & Thompson, 2003; Thompson, Gentner, & Loewenstein, 2000) successfully taught negotiation strategies by analogical encoding; that is, by having learners compare exemplified strategy applications.

Research on Cognitive Load Theory

Cognitive load theory—a theory based on assumptions about working memory capacity and learning—began to emerge in the mid-1980s (Sweller, Ayres, & Kalyuga, 2011). One of this theory’s instructional effects is the worked-example effect. In their seminal studies, Sweller and Cooper (1985; Cooper & Sweller, 1987) compared learning by problem solving with example-based learning. For example, in Sweller and Cooper (Exp. 3), ninth-grade students learned to solve algebraic equations under two conditions. First, all students saw worked examples as part of the introduction to the learning contents. Then, in the conventional problem-solving condition, the students worked on eight problems representing four problem types. In the worked example condition, the students worked on the same eight problems, except that the first problem of each structurally identical problem pair had been worked out. In a posttest, the example condition produced fewer errors than the conventional condition. In addition, learners in the example condition spent less time on the acquisition phase and on the posttest problems.
On the theoretical level, Sweller and Cooper (1985) argued that the usual method of problem solving directs attention to search processes but not to aspects that are directly relevant for schema acquisition (i.e., learning). Hence, problem solving induces learning-irrelevant (i.e., extraneous) cognitive load. Worked examples, in contrast, free cognitive capacities for learning-relevant (i.e., germane) load (Sweller, van Merriënboer, & Paas, 1998). Examples allow learners to acquire knowledge about problem states, operators, and the consequences of the application of certain operators. These knowledge components are, in turn, organized into schemas that can be used for later problem solving. In light of expected motivational problems with worked examples because they do not induce activity, Sweller and Cooper (1985) used isomorphic example-problem pairs. If the learners know that a similar problem is to be solved afterwards, they should be motivated to process the preceding example.

Research has made significant progress since the emergence of these historical roots. These advances relate especially to theoretical foundations and to instructional guidelines that allow for optimizing the potential of instruction by examples. These advances are discussed in the following sections.

THEORETICAL FOUNDATIONS

Renkl (2014) recently proposed a theory of example-based learning. Two important building blocks of this theory are presented in this section: the appropriate place of example-based instruction in the course of skill acquisition, and explanations of the effectiveness of instruction by examples.

The Appropriate Place for Example-Based Instruction in the Course of Skill Acquisition

There are several skill acquisition models in which example-based learning plays a significant role (Anderson, Fincham, & Douglass, 1997; Schunk & Zimmerman, 2007; VanLehn, 1996). As each of these models makes sensible assumptions not included in other models, Renkl (2014) formulated an integrative model including four stages. Note that this model only applies when the domain principles are presented up front, which is the standard in example-based learning (Renkl, 2014).

In a first stage (principle encoding), learners acquire some basic declarative knowledge about a domain, particularly about the domain principles that should later guide problem solving (VanLehn, 1996). For example, they may learn about Kuhn’s (1991) theory of scientific argumentation (Schworm & Renkl, 2007). In this stage, the learner does not yet know how to apply principles.

In the second stage (relying on analogs), learners turn their attention to problem solving (VanLehn, 1996). They may first encounter examples printed in a textbook—as is often the case in mathematics textbooks after introducing a topic—or presented “live” by a teacher or, in classroom, by a peer student. To take up the example of argumentation, students may observe instantiations, such as exemplary models of proper scientific argumentation. These examples are encoded by the learners, but the quality of this encoding depends on the quality of the learners’ self-explanations (Chi et al., 1989). If problems (or just part of one) have to be solved, it is primarily done by analogy (Ross, 1989; VanLehn, 1998). Hence, problems are solved not solely on the basis of applying general principles (e.g., theorems, laws) but (also) by referring to concrete examples (see Reeves & Weisberg, 1993). Learners do not necessarily disregard principles, but
they are nevertheless first guided by analogs that are checked for suitability (Holyoak, 2005; VanLehn, 1998). Analogs can then remind learners of the relevant underlying principles if the analog is encoded with references to the underlying domain principles. Successful problem solving with reference to analogs leads to generalized schemas, at least if the initial encoding of multiple examples has not yet resulted in generalized schemas (Ross, 1989). Both initial example encoding and later retrieval for problem solving contribute to schema formation.

When learners develop declarative rules of action in a content area (Anderson et al., 1997), they have entered the third stage (forming declarative rules). They have acquired verbalizable rules on how to act or to solve (parts of) problems. For example, a learner having observed an argumentation model might be able to state the rule, “If considering counterarguments against my position I will (try to) disconfirm them.” Ideally, such rules are embedded in schemas that allow for categorizing problem cases irrespective of their superficial features (e.g., the topic that is being disputed). In both the second and third phases, learners typically correct their still somewhat faulty declarative knowledge when they encounter difficulties in problem solving (cf. VanLehn’s, 1996, 1998, impasse-driven learning).

In the fourth and final stage (fine tuning: automation and flexibilization), learners have already learned to solve structurally identical problems because they have acquired schemas that enable them to correctly identify certain problem categories and apply corresponding solution procedures. There are, however, two ways in which skills can be optimized during problem solving. First, the procedures involved in the skill can become automatic (i.e., proceduralized rules are formed), resulting in faster performance and minimal working memory demands. In addition, several subsequent solution steps can be chunked into one (larger) step. If certain problems recur, the solution can also be directly retrieved from memory (Anderson et al., 1997). Second, learners might adapt their skill to changes in contextual conditions or even to changes in the structural features of the problems to be solved (Schunk & Zimmerman, 2007). Learners gain flexibility. These two aspects of improvement (i.e., automation and flexibility) are not independent. If working memory resources are saved by automation, more capacity remains for engaging in reasoning processes that render a skill more flexible.

As is the case with related models (e.g., VanLehn, 1996), there are no strict boundaries between these stages. It is especially when learners are acquiring complex skills that they might be at an early stage with respect to some sub-skills, whereas other sub-skills might already be automatized.

Instruction should concentrate on examples in the second phase (relying on analogs). Learners are shown how principles are applied, concrete examples are encoded and, ideally, related to principles in generalized schemas. In the next phase (forming declarative rules), teaching by examples is still relevant when a learner is acquiring declarative rules on when to apply a certain principle (e.g., in the case of a certain problem category) and when it should not be applied (e.g., in the case of a related, but different problem category). In advanced skill acquisition, when automation and flexible application are the main goals, teaching by examples should not be the primary method. Instead, problem solving is superior in most cases.

**Explanations of the Effectiveness of Instruction by Examples**

When problem solving rather than example study is required at the beginning of skill acquisition, learners very often lack understanding of the domain principles and
their application (Renkl, 2014). They therefore use shallow strategies, for example, a key word strategy (i.e., selecting a procedure such as addition via a key word such as “together” in the cover story of a problem), a copy-and-adapt strategy (i.e., copying the solution procedure from a presumably similar problem and adapting the numbers in the procedure), or a means-ends analysis focusing on superficial problem features. Due to their lack of understanding, they cannot rely on domain strategies in their problem solving efforts that refer to the principles to-be-learned. However, as employing general or shallow strategies for problem solving does not deepen domain understanding, it can be classified as an activity inducing extraneous load. Worked examples free learners from such extraneous activities. They leave cognitive resources available for self-explanation, that is, for explicating the rationale of the solution for oneself, especially under reference to the underlying domain principles. Once learners have understood the domain principles and their applications, it makes sense to encourage them to solve problems requiring the application of those principles. In short, learning from example is only advisable during initial skill acquisition.

Note that self-explaining is regarded as a crucial factor in example-based instruction. However, not all learners actively self-explain when given examples. For them, this learning approach is only fully exploited when self-explaining is supported by prompting or training. Asking learners to self-explain examples is also of special importance because abstract principles and concrete exemplars become interrelated, and learners gain understanding on how to apply principles in problem solving.

Whereas the preceding mechanisms focused on example encoding, another important learning mechanism is related to the later use of encoded examples, as revealed by analogical reasoning research (e.g., Ross, 1989). When a transfer problem is to be solved, potentially relevant analogs are activated and selected. The problem to-be-solved is mapped to the analog. If the learner identifies structural features shared by the problem and the analog (e.g., common domain rule), a schema that abstracts from surface features (e.g., objects and numbers) can result from such a mapping process (e.g., Ross, 1989; Ross & Kennedy, 1990). Whereas Sweller and Cooper (1985) provided example-problem pairs in order to heighten motivation to study the example, analogical reasoning research shows that such an arrangement also bears fruit because students rely on the preceding example when trying to solve a problem, map the problem to example, and thereby construct generalized knowledge structures that can be used for later problem solving. Hence, the construction of generalized schemas can occur during example encoding (via self-explanation) as well as during subsequent problem solving (as discussed in this paragraph).

In summary, examples relieve learners from the demands of problem solving that is mainly driven by superficial strategies, especially during initial skill acquisition when they lack understanding. The latter strategies do not really deepen understanding. When studying examples, learners have enough capacity to gain understanding by self-explanations that interrelate abstract principles and concrete exemplars. Finally, generalized schemas are constructed when learners refer to examples in later problem solving.

**EVIDENCE-BASED PRINCIPLES FOR INSTRUCTIONAL DESIGN**

In this section, I describe the prescriptive aspect of Renkl’s (2014) theory of example-based learning. The huge body of research findings on factors that moderate the effectiveness of example-based instruction has been amalgamated into instructional
guidelines. Instructional guidelines have only been formulated when the findings in question did not originate merely from one research group (that typically relies on one experimental paradigm and/or uses one learning domain). The following nine guidelines and their boundary conditions are outlined: self-explanation guideline, explanation-help guideline, example-set guideline, easy-mapping guideline, meaningful-building-blocks guideline, studying-errors guideline, model-observer similarity guideline, imagery guideline, and interleaving-by-fading guideline. Note that due to space restriction, just exemplary studies are cited when discussing the instructional guidelines.

**Self-Explanation Guideline**

As the learners’ self-explanation activities are crucial to fully exploit the potential of example-based instruction, this concept was discussed previously (Chi et al., 1989; Renkl, 1997; see also Chapter 16 in this volume). In their seminal study on the self-explanation effect, Chi et al. (1989) identified individual differences in how intensively learners self-explained the solution steps of worked physics examples. Successful learners studied the examples longer and explained them more actively to themselves; that is, they tried to figure out the rationale of the solution procedure. Renkl (1997) showed that even when the example study time was kept constant, self-explanation activity is associated with learning outcomes. Self-explanations fall into two main categories (Gerjets, Scheiter, & Schuh, 2008; Nokes-Malach, VanLehn, Belenky, Lichtenstein, & Cox, 2013): elaborating on examples and comparing examples.

**Elaborating on Examples**

Learners can engage in two particular types of self-explanations when assigning meaning to examples (see Conati & VanLehn, 2000): principle-based explanations and goal-operator elaborations. Principle-based explanations refer to relating problem solutions to abstract domain principles (e.g., mathematics theorem, physics law; Atkinson, Renkl & Merrill, 2003; Renkl, 1997). Such an activity fosters the principle-based understanding of examples. Figure 15.1 provides a prompt (see lower left corner, above the note box) that asks for an instructional design principle that explains why one example version is superior to the other, which in this case is the principle of meaningful building blocks (Hilbert et al., 2008).

Goal-operator elaborations are also a means by which learners can assign meaning to operators by identifying the subgoals these operators achieve (e.g., in a probability example, the elaboration might be “By subtracting the probability of red items from 1, we get the probability of non-red items”). This activity fosters the representation of goals to be achieved and of knowledge about operators for achieving these goals. There is ample evidence that such elaborations foster transfer to novel problems (Catrambone, 1996; Chi et al., 1989; Conati & VanLehn, 2000; Renkl, 1997; Renkl, Stark, Gruber, & Mandl, 1998).

There are two main ways to foster principle-based self-explanations and operator-goal elaborations: training and prompting. A training approach specifically tailored to example-based learning was employed, for example, by Renkl et al. (1998). They analyzed the effects of a short self-explanation training session (10–15 min.) focusing mainly on goal-operator elaborations in interest calculation. This intervention
included the following components: (a) providing information on the importance of self-explanations (i.e., informed training), (b) modeling self-explanations (one worked example from interest calculation), and (c) coached practice (with another worked example). This intervention had a strong effect on self-explanation activities and on the transfer to similar problems, as well as on novel problems (Stark, Mandl, Gruber, & Renkl, 2002). Prompting interventions were employed in most of the studies designed to experimentally test the effects of self-explanation activities (e.g., Atkinson et al., 2003; Schworm & Renkl, 2006, 2007). As computer-based learning environments were employed in many studies, learners typically had to type their self-explanations into text boxes (see Figure 15.1). Self-explanation activity is sometimes supported by menus that provide a list of potential principles or goals (e.g., Conati & VanLehn, 2000).

**Comparing Examples**

Comparing examples can induce an abstract schema that includes a general principle (e.g., Gick & Holyoak, 1983; Holyoak, 2005, 2012). In the future, such a schema can be used to solve transfer problems. It is important to note that the two types of self-explanations (i.e., example elaboration and example comparison) can actually serve the same function (Renkl, 2015). Principle-based self-explanations relate concrete examples or worked steps to abstract principles; the same effect might result from comparing two (or more) examples or steps and noting that they instantiate the same principle (Nokes-Malach et al., 2013).

Such example comparisons are typically *within-category comparisons* (Gerjets et al., 2008). A category relates to a set of problems solvable by applying the same set and sequence of principle(s). For example, when learners compare probability examples of a certain type (e.g., order relevant, without replacement), they can see that the numbers and objects used are irrelevant for selecting the appropriate solution procedure and that these features can vary between problems from the same category. Ideally, the learners’ attention is directed to the structural features that remain constant across problems of the same category (e.g., order relevant, without replacement) and determines the appropriate solution procedure (see, e.g., Berthold & Renkl, 2009; Gerjets et al., 2008). A focus on structural features fosters transfer (e.g., Gentner et al., 2003; Gerjets et al., 2008; Nokes-Malach et al., 2013; Thompson et al., 2000).

Besides comparing isomorphic examples, there are comparisons that can be labeled as *critical-feature comparisons*. In these cases, comparisons are guided so that specific aspects that differ between examples become salient and are encoded as important features (cf. the contrasting cases model by Bransford & Schwartz, 1999). For example, probability examples from different but easily mixed-up categories such as “order relevant” and “order irrelevant” are presented so that the learners notice that when solving probability problems, it is important to check whether the order is relevant or not (between-category comparison; Gerjets et al., 2008). In this case, the critical feature is the “relevance of order.” Rittle-Johnson, Star, and colleagues (Rittle-Johnson & Star, 2009; Rittle-Johnson, Star, & Durkin, 2009) encouraged their learners to explain the difference between two worked solution methods for the same problem and the conditions that must be met so that the more parsimonious method can be applied. In this case, the critical features are the conditions that must be met when applying the more parsimonious solution method. Flexible problem solving is taught by this comparison procedure.
From an instructional point of view on comparing examples, typical prompts that worked well in the within-category comparison studies are those that ask for the examples’ communalities and differences to be compared. In some cases, prompts ask the learner to identify the principle that applies to the examples at hand (e.g., Thompson et al., 2000). The prompts for critical-feature comparisons are formulated quite diversely and have been tailored to the specific learning goal (i.e., the critical features to be identified). For example, Rittle-Johnson and Star (2009) asked their learners to compare two solutions from two fictitious students (Patrick and Nathan) by the following prompt: “What must be true about an equation for Patrick’s way to be easier than Nathan’s way?” (p. 533).

**Boundary Conditions**

Beyond the numerous positive findings on eliciting self-explanations, there are several studies that failed to observe positive effects on learning outcomes (e.g., Gerjets, Scheiter, & Catrambone, 2006; Große & Renkl, 2006; Mwangi & Sweller, 1998). Renkl and Scheiter (in press) proposed several guidelines for effective prompts: They should be formulated so that students provide mainly correct responses. The prompts should not induce excessively high cognitive load, which might be the case when they are combined with complex and sub-optimally designed learning materials. Just-in-time prompts (in contrast to prompts provided *a priori*) reduce self-regulation demands so that learners are more likely to profit from them.

**Explanation-Help Guideline**

Relying solely on self-explanations might be sub-optimal. Learners are sometimes unable to self-explain a solution step, or their self-explanations will be incorrect, which can hinder learning (e.g., Berthold & Renkl, 2009). Hence, help in the form of instructional explanations makes sense. Note that in this context, help means the provision of instructional explanation as a supplement to self-explanations.

In Renkl’s (2002) experiment on help, the learners studied probability examples and had the opportunity to click on an “Explanation” button. In this case, a “minimalist” explanation of a solution step that just contained the underlying principle was provided. When the learners requested more extensive support, they were shown how elements of the worked examples matched the formula elements and how probability could be determined. The learners with the opportunity to request such help outperformed those without help in a subsequent posttest with transfer problems. There are several additional studies demonstrating the positive effects of help in the form of instructional explanations added to examples (e.g., Atkinson, 2002; Myers, Hanson, Robson, & McCann, 1983; Ross & Kilbane, 1997).

There are, however, certain boundary conditions for the explanation-help guideline. In their meta-analysis, Wittwer and Renkl (2010) identified factors moderating the effects of instructional explanations in example-based learning. Positive effects are found in the following cases:

1. Help is effective when conceptual understanding is emphasized as the learning outcome (in contrast to, e.g., procedural knowledge).
2. Help fosters learning when there is no simultaneous self-explanation elicitation (typically by prompts). The two types of support are redundant.
3. The effects of help are more reliable if it is provided automatically (instead of on learner demand).
4. Help is effective with mathematical content. A tentative, yet to be tested explanation is that learners perceive mathematics as particularly difficult and feel insecure when left to their own devices (Wittwer & Renkl, 2010).

In summary, instructional explanations as help often have restricted or even negative effects in example-based instruction. However, under certain circumstances (e.g., conceptual understanding as learning goal; no self-explanation prompting) they can supplement self-explanation activities and thereby foster learning outcomes.

**Example-Set Guideline**

One means of directing learners’ attention to specific aspects (e.g., structural aspects of problem categories) is to assemble sets of examples in specific ways. Quilici and Mayer (1996) used structure-emphasizing example sets. Such sets arrange examples so that (a) each problem category is exemplified by a set of different cover stories (i.e., surface); and (b) the same set of cover stories is used across the problem categories. The learners can see that cover stories and structure do not necessarily co-vary and that relying on surface features does not necessarily help to find the correct solution procedure. Two experiments showed the positive effects of structure-emphasizing sets with respect to sorting problems according to their structure and solving transfer problems (compared to a control condition receiving very similar surface stories for all examples of a given category; for replication, see Quilici & Mayer, 2002).

Paas and van Merriënboer (1994) presented geometry examples from three categories to their learners. In a low-variability condition regarding the problem sequence, pairs of isomorphic worked examples were presented so that within each pair, just the numerical values differed. In the high variability condition, the types of values to be determined varied from example to example. As predicted, high variability examples led to superior transfer performance.

There are boundary conditions for the effectiveness of example sets. Positive effects are unstable if self-explanations directed to example comparison are not explicitly fostered. Scheiter, Gerjets, and Schuh (2003) detected the positive effects of structure-emphasizing example sets only when the learners were instructed to compare the examples with respect to similarities and differences. Similarly, analogical reasoning research has shown that providing multiple examples must be combined with comparison prompts to achieve transfer effects (e.g., Catrambone & Holyoak, 1989; Gentner et al., 2003; Gerjets et al., 2008). In addition, more support leads to better outcomes than little support in example comparison (e.g., Gentner et al., 2003).

In summary, example sets—typically designed to make structural aspects more salient—can have positive effects on learning outcomes. However, this is not always the case. To assure the positive effects of example sets, prompts or training interventions can be used to foster example comparison processes.

**Easy-Mapping Guideline**

The positive effects of worked examples is lost when learners have difficulty mapping different information sources to each other, such as figures and arithmetical equations in geometry problems (Tarmizi & Sweller, 1988). In an effort to map the different information sources
sources, learners with difficulties engage in extensive search that requires so much cognitive capacity (i.e., induces extraneous load) that productive self-explanations are more or less blocked. One possibility to make it easier to interrelate different information sources is to physically integrate them (e.g., writing the size of an angle in a geometry example directly into the figure). Such mapping facilitation makes cognitive resources available so that self-explanations can occur. Hence, facilitating mapping enhances learning outcomes substantially (Mwangi & Sweller, 1998; Tarmizi & Sweller, 1988; Ward & Sweller, 1990; see also Mayer & Moreno, 2003, for similar results in their research program).

An integrated format is not the only means of facilitating mapping between information sources. The capacity for initial information processing is distributed over several sensory subsystems (e.g., Mayer & Moreno, 2003; Rummer, Schweppe, Fürstenberg, Scheiter, & Zindler, 2011). Hence, information processing can be facilitated by providing spoken text together with a figure, instead of presenting both types of information visually (i.e., printed text). For example, Mousavi, Low, and Sweller (1995) compared in several experiments two conditions: (a) geometry proof examples were presented visually only (i.e., figure and written proof statements); (b) geometry proof examples were presented in a mixed modality; that is, the figure was printed and the proof statements provided by a tape recorder. In six experiments, Mousavi et al. showed that in the mixed presentation mode, learners solved the posttest problem faster (with low overall failure rates in both conditions). Jeung, Chandler, and Sweller (1997) qualified these findings. In their three experiments in which the difficulty of mapping between information sources was varied, they showed that for visually complex, unfamiliar materials, the superiority of auditory explanations on visually presented examples disappeared. It only reappeared when electronic flashing was additionally used to show to which part of the diagram the spoken text was referring.

What are this guideline’s boundary conditions? An open question that cannot be answered on the basis of available empirical evidence is when it is best to integrate; when best to use dual-mode and signaling; or when best to use other instructional procedures, such as color coding and/or flashing (see Figure 15.2). Pragmatic answers suggest using an integrated format in cases where an auditory presentation is not or hardly possible, due to technical restrictions. Integrated formats cannot be used if elements in one representation mode do not correspond to certain, well-circumscribed parts in the other representation mode. For example, in Figure 15.2, the “20” in the denominator of the resulting probability corresponds to the 20 branches of the tree-like structure. In these cases, a “classical” integrated format is hardly possible. However, there is no principled guideline showing us when to use which support procedure.

In a nutshell, in order to support learners when studying examples with different information sources (e.g., figures and arithmetical equations), it is advisable to facilitate mapping. Such facilitation can be accomplished by several instructional procedures, such as integrated format, color coding, flashing, or combining auditory and visual presentation formats.

**Meaningful-Building-Blocks Guideline**

Sometimes, students have encoded solution procedures for certain problem types as a “fixed chain” of steps (e.g., in probability learning: “first, multiply the probabilities; second, add them; third, subtract from this sum of the product determined in the first step”). If the students do not understand the meaning of the single steps, they cannot flexibly reassemble them for a novel problem in which, for example, the sequence of
the steps has to be changed or steps have to be left out. In other words, transfer is likely to fail if the learners have not encoded the individual steps in a chain as meaningful building blocks. Hence, it is beneficial to present examples so that sub-components can be identified easily as meaningful building blocks. Catrambone (e.g., 1996, 1998) demonstrated in a series of experiments that the ability to assemble new procedures can be fostered by making subgoals in a worked solution salient, either by visually isolating them (e.g., making circles around them) or by assigning a label. Catrambone (1996) found that salient subgoals lead to self-explanations about what these steps accomplished. Learning outcomes were enhanced as a result. If worked examples consist of dynamic visualizations (i.e., video or animation models), segmenting—that is, pausing after meaningful event units—helps learning, in particular for learners with low prior knowledge (Spanjers, van Gog, Wouters, & Van Merriënboer, 2012; Spanjers, Wouters, van Gog, & Van Merriënboer, 2012; see also Ertelt, Renkl, & Spa da, 2006).

In some cases, learners are barely able to identify meaningful building blocks of worked solutions because the instructional materials use formulas that are computationally efficient but opaque. Beginning learners can hardly understand—and later reconstruct if necessary—such molar formulas. For example, the problem in Figure 15.1 is efficiently solved by the formula shown on the left side. The formula is called molar because it synthesizes a number of more fine-grained modular steps (see Figure 15.1 on the right side). The solution’s rationale can be understood much better when learning from the solution on the right side. Several experimental studies have shown that breaking the molar solutions into modular units (as shown in Figure 15.1) leads to better performance on isomorphic and novel problems (Atkinson, Catrambone, & Merrill, 2003; Gerjets, Scheiter, Catrambone, 2004, 2006). Hence, computationally-not-that-efficient modular solution procedures are more favorable for beginners (of course, the efficient molar solutions might be more convenient for advanced learners).

Boundary conditions refer to the type of content area. Relevant findings were mainly obtained in mathematical content areas. The findings of Spanjers et al. (2011, 2012) and of Ertelt et al. (2006) on segmenting dynamic worked examples suggest that video
models on complex skills also profit from making the meaningful building blocks salient via segmenting. However, segmenting might have also helped learning by buffering the disadvantages of transient information in presented videos or animations (Spanjers et al., 2012). Further research should thus explicitly test the meaningful-building-blocks guideline with diverse types of worked examples.

In summary, it is recommended to design examples, especially if they are complex, in a way that the single building blocks of skills become salient. Emphasizing meaningful building blocks is particularly important in enhancing learners’ ability to rearrange single moves in order to solve novel problems. How to make building blocks salient is best known for the case of mathematical learning materials.

**Studying-Errors Guideline**

Typical examples reveal correct performance or solutions. As errors can be a productive element in learning, it might nevertheless be fruitful to include errors in example-based instruction (VanLehn, 1999). Actually, several studies have found that studying correct and incorrect worked solutions is more beneficial than self-explaining correct worked solutions only (e.g., Adams et al., 2014; Durkin & Rittle-Johnson, 2012; Siegler & Chen, 2008). There are similar findings from observational learning research. Some studies compared mastery models that demonstrated smooth performance and coping models that initially showed difficulties (i.e., made errors) and how they can be overcome. Learners usually profit from coping models in particular (Kitsantas, Zimmerman, & Cleary, 2000; Schunk, Hanson, & Cox, 1987). For example, Zimmermann and Kitsantas (2002) taught college students writing skills by models demonstrating a revision strategy. The mastery model performed this strategy flawlessly with nine training problems. The coping model made and corrected errors on the initial revision problems, but gradually reduced them. The students who had observed the coping model displayed better learning outcomes than their counterparts who had observed a mastery model.

Of course, coping and mastery models differ in more than whether or not errors or sub-optimal moves are shown. In particular, a coping model also demonstrates how to cope with difficulties. Nevertheless, these findings are in line with the aforementioned studies on studying errors in examples.

The findings of Große and Renkl (2007) reveal boundary conditions for this guideline. In two laboratory experiments, a mixture of correct examples and examples with errors, as compared to correct examples only, helped learners with good prior knowledge, but impeded learners with poor prior knowledge (for similar findings in the field, see Heemsoth & Heinze, 2014). Providing errors in worked examples too early in the learning process (i.e., when prior knowledge is too low) might overwhelm learners. One possibility is to provide more support for weaker learners. Große and Renkl (2007) found that explicitly marking errors (versus not doing so) supported especially learners with low prior knowledge.

In summary, including errors in examples can foster learning. Less advanced learners, however, can be overwhelmed by the demands to process erroneous examples. In this case, help such as marking the errors is necessary.

**Model-Observer-Similarity Guideline**

In social-cognitive theorizing about acquiring cognitive skills from exemplary models, one of the classical moderators of model effects is the similarity between the model
and observer (e.g., Bandura, 1986; Schunk, 1987, 1999; Schunk & Zimmerman, 2007). If the model that exhibits a to-be-learned problem solution is too dissimilar (especially too advanced), the observer might not believe that s/he is able to demonstrate the appropriate behavior by herself/himself (i.e., lack of self-efficacy; Schunk & Hanson, 1985). For example, Ryalls, Gul, and Ryalls (2000) found that 14- to 18-month-old children learned three-step sequences better from peer models than from adult models. Braaksma, Rijlaarsdam, and van den Bergh (2002) provided both a competent and a non-competent model to students in order to learn argumentative writing. In one condition, the learners were instructed to focus specifically on the competent model, and in another condition, on the non-competent model, when comparing both models. Weak students profited more from focusing on the non-competent model than on the competent model. Stronger students profited more from focusing on the competent model. This pattern of findings was interpreted as a similarity effect in observational learning.

The coping model effect discussed above was also interpreted as a similarity effect in the literature on socio-cognitive learning (e.g., Schunk, 1999). However, it is not clear whether the similarity and/or the shown errors (and how they are overcome) are crucial. In this context, the findings of Schunk and Hanson (1985) are interesting. They showed that elementary students learning subtraction skills profited more from (same sex) peer models, either coping or mastery, than from an adult teacher model (mastery). Obviously, similarity plays a role beyond the studying-errors effect.

What are the boundary conditions of this effect? In particular, when examples in the form of realistic models are employed, it is highly plausible that the model-observer similarity is an important factor. However, Hoogerheide, Loyens, Jadi, Vrins, and van Gog (in press) did not find a similarity effect in the case of written worked examples. Beyond this restriction, it is at least thus far unclear which type of similarity is most important and which features of potential similarity are more or less irrelevant (e.g., age, gender, language accent, ethnicity).

On the whole, the available empirical evidence makes it very probable that model-observer similarity is a crucial factor when video examples are used. However, further research should determine which specific aspects of similarity are crucial.

**Imagery Guideline**

Sweller and colleagues have conducted a number of experiments on imagery in example-based instruction (e.g., Cooper, Tindall-Ford, Chandler, & Sweller, 2001; Ginns, Chandler, & Sweller, 2003; Tindall-Ford & Sweller, 2006). The imagery procedure included first to read a worked solution, second to turn away from the screen, and third to imagine performing the solution procedure. Similarly, Scheiter, Gerjets, and Catrambone (2006) had some of their learners imagine the event flow described in the worked examples. Empirical evidence clearly shows that imagery can foster learning. Some studies—albeit in the field of perceptual and motor skills—have shown that mental imagery can have effects similar to those from actually performing (e.g., Corriss & Koss, 1998).

Studies by Sweller and colleagues (e.g., Cooper et al., 2001; Ginns et al., 2003; Tindall-Ford & Sweller, 2006) have also shown that the imagery effect has boundary conditions. A lack of prior knowledge prevents the learners from actually complying with the imagining instruction. They simply cannot imagine the solution when looking away from the example. Hence, imagery instructions should be not given too early.
in the course of skill acquisition. One solution is to first provide an example for pure study and then an example for imagery (Ginns et al., 2003).

**Interleaving-by-Fading Guideline**

In the classical studies on the worked-example effect (e.g., Cooper & Sweller, 1987; Sweller & Cooper, 1985), the example condition included a combination of example study and problem solving. More specifically, isomorphic example–problem pairs were employed in an attempt to motivate example processing. Analogical reasoning research shows that solving a problem isomorphic to a preceding analog fosters schema induction (see Holyoak, 2005, 2012; Ross, 1989). Bandura (1986) claimed that learners need practice between observations of models. The resulting difficulties show learners where they need to direct their attention in subsequent models to repair their deficits.

Pashler et al. (2007) recommended in their evidence-based practice guide for teachers to interleave worked solutions with problem solving, as one of seven central recommendations (similarly Cromley & Byrnes, 2012). Such interleaving is to be implemented by problem-example pairs. However, pairing might not be the best method of interleaving.

Other researchers have proposed using a fading procedure to productively combine example study and problem solving. In such a fading procedure, a complete example is presented first. Second, an isomorphic example is presented in which a single step is omitted; after trying to supplement the faded step, the learner receives feedback about the correct solution. Then, in the following examples, the number of blanks rises step by step until just the problem formulation is left—that is, a to-be-solved problem. Such fading is also beneficial because it provides an answer to the question of how to structure the transition from worked examples in earlier stages of skill acquisition to problem solving in later stages (cf. the expertise-reversal effect by Kalyuga et al., 2003). It is important to emphasize that such fading also leads to interleaving. For example, if learners come to a worked example with one step to be determined (and two steps worked out), they will again encounter worked steps after the first problem-solving demand. The main difference between fading and example–problem pairs is constant versus increasing problem solving demands over time.

A number of experiments have shown that fading worked solution steps lead to better learning outcomes than example–problem pairs (e.g., Atkinson et al., 2003; Renkl, Atkinson & Große, 2004; Renkl, Atkinson, Maier, & Staley, 2002). However, there are also experiments that identified no positive fading effects (e.g., Moreno, Reisslein, & Ozogul, 2009; Reisslein, Atkinson, Seeling, & Reisslein, 2006). A problem in designing an effective fading procedure is that it should be tailored to the learner’s prior knowledge. A learner who has not yet gained a basic understanding of a principle and its application should study further worked steps and not be exposed to a corresponding problem-solving demand; once the student displays such understanding, s/he should try to apply this knowledge in problem solving (Renkl, 2014). Hence, fading steps can come too early (in the case of low prior knowledge) or too late (in the case of high prior knowledge). In most studies, there was a fixed fading procedure that was not explicitly matched *a priori* to the study participants’ knowledge level. To put it somewhat pithily, researchers needed good intuition and good luck for their fading scheme to fit the participants’ knowledge level. Hence, a lack of fit between the fading procedure and the learners’ knowledge level might explain why some studies failed to detect positive fading effects.
Salden et al. (2010) optimized fading by making it adaptive to the individual learners on the basis of Cognitive Tutors’ intelligent tutoring technology (Koedinger & Corbett, 2006). They compared an adaptive fading procedure with a fixed fading procedure that was the same for each learner in the respective condition, and a pure problem-solving condition (i.e., the standard procedure of Cognitive Tutor lessons). In two experiments (laboratory and field), learners in the adaptive fading condition performed best in a delayed posttest.

The major boundary conditions have been discussed: The fit between the fading procedure and learners’ prior knowledge level. To sum up: a fading procedure is a productive means of interleaving example study and problem solving. However, fixed and non-tailored fading procedures run the risk of not fitting the learners’ knowledge level. Hence, adapting fading, if feasible, is especially effective.

RECENT DEVELOPMENTS IN RESEARCH ON WORKED EXAMPLES

As research on worked examples is such an active and dynamic field, several key developments have evolved in recent years, three of which are outlined here.

Example-Based Learning and Embodiment

Several recent studies relied on theories of embodied cognition (e.g., Glenberg, 2010) to boost the learning effects of worked examples. These theories assume that cognition is grounded in bodily, sensomotoric experiences. For example, Agostinho et al. (2015) and Hu, Ginns, and Bobis (2015) found that instructing learners to trace the visual parts of worked examples (temperature graphs or geometrical figures) with their index fingers fosters learning outcomes.

A number of studies have examined whether learning is fostered by enriching worked examples with human-like characteristics (e.g., video models vs. written models, showing faces, using gestures). Surprisingly, several studies observed very restricted or even no effects of such human-like characteristics (e.g., Hoogerheide, Loyens, & van Gog, 2014: video models vs. written example; Ouwehand, van Gog, and Pass, 2015: gestures in video models; van Gog, Verveer, & Verveer, 2014: showing a model’s face). As some of these negative findings seem to stand in contrast to the embodiment principle in multimedia learning (Mayer, 2014), further research on the boundary conditions of the effects of human-like characteristics is needed.

In summary, the boundary conditions of embodiment effects in example-based learning remain unclear. Presently, it seems more promising to apply “embodiment enrichments” to learners’ study of examples (e.g., finger tracing) than to the design of the examples themselves.

Innovative Uses of Worked Examples

The positive learning effects of worked examples have recently inspired some researchers to unconventional applications; that is, they employed worked examples for instructional purposes other than to provide solutions to problems from a specific domain such as mathematics, law, or physics.

Hefter and colleagues (e.g., 2015) used worked examples in form of videos showing two persons arguing about a controversial ecology topic. The main model person
(expert) demonstrated sophisticated epistemological understanding (evaluativist level) and high intellectual values (i.e., regarding intellectual engagement as worthwhile) while discussing with a novice person. These examples successfully initiated changes in high school students’ epistemic orientations and intellectual values.

Another unconventional use of worked examples refers to eye-movement modeling examples (EMME). These EMME are used in two ways. First, EMME can display the eye movements of a successful learner or of an expert behaving didactically. These eye movements are superimposed upon the learning materials. Important information is cued thereby, which can help learning about, for example, different types of fish locomotion (e.g., Jarodzka, van Gog, Dorr, Scheiter, & Gerjets, 2013). Second, EMME can be presented as a type of pre-training; that is, it is used before learners study the relevant learning materials. For example, Mason, Pluchino, and Tornatora (2015) provided a pre-training (lasting about 3 min.) presenting a model emphasizing the integration of text and pictures in learning materials by moving her eyes back and forth between the two information sources. In a subsequent learning phase with different learning materials, high-school students showed more integrative text-picture processing and superior transfer in a final posttest.

As in the case of EMME pre-training, Glogger-Frey, Fleischer, Grüny, Kappich, and Renkl (2015) used examples to prepare learners for later learning. More specifically, the learners should study contrasting examples (cf. contrasting cases; Bransford & Schwartz, 1999) in order to prepare for subsequent direct instruction. This idea was motivated by observing the restriction of many inventing (and productive-failure) studies (e.g., Schwartz & Martin, 2004), showing that an exploratory phase with specially designed contrasting problems can productively prepare learners for later direct instruction: Often the comparison conditions did not strictly control for “time-on-contents” (see also Sweller, Kirschner, & Clark, 2007). Glogger et al. (2015) asked whether contrasting worked examples might not better prepare for later learning from direct instruction than inventing. Replacing inventing by worked examples led to superior preparation for later learning, as revealed in the final learning outcomes (e.g., Glogger-Frey et al., 2015).

In summary, positive findings on example-based learning have led to a number of innovative and productive uses of worked examples in recent years. thereby expanding the range of application contexts for instruction by examples.

**Worked Examples in Subject Education**

Initial research on worked examples was mainly conducted by psychologically oriented researchers. As many of these studies were done with mathematical learning contents, the findings on example-based learning have been influencing mathematics educators for many years (e.g., Reiss & Renkl, 2002). Meanwhile, however, other areas of subject education have also been inspired by worked-example research. For example, in their recent review on physics education, Docktor and Mestre (2014) emphasized the relevance of example-based instruction for fostering problem-solving skills, pleading for more research on how to specifically exploit this method in physics instruction. In medical education, there have been many studies and articles describing how to productively use worked examples in this domain (e.g., Chamberland et al., 2015; Stark, Kopp, & Fischer, 2011). Engineering education is another field in which worked examples have been successfully employed (e.g., Johnson, Riesslein, & Reisslein, 2014). Finally, Mugford, Corey, and Bennell’s (2013) theoretical framework for police training...
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recommends the use of worked examples. In summary, the numerous positive findings on example-based learning have influenced many subject educators, which can be seen as an important contribution to the field of education.

OUTLOOK: PROPOSING FRUITFUL LINES OF FURTHER RESEARCH

Three issues are proposed as representing fruitful lines of further research. These lines should advance the theoretical foundation, instructional relevance, and the impact on the practice of example-based instruction.

Theoretical Foundation

Diverse research traditions are relevant when considering example-based instruction. In recent years, classical research on worked examples was especially enriched by ideas from research on observational learning (e.g., van Gog & Rummel, 2010) and on analogical reasoning (e.g., Nokes-Malach et al., 2013). Renkl (2014) proposed a theory of example-based learning that took initial steps towards integrating these different theoretical perspectives. Nevertheless, many detailed questions remain open that require further theoretical and empirical analyses. Some of these questions (e.g., the relevance of the model-observer similarity for written worked examples) have already been addressed in recent studies (e.g., Hoogerheide et al., 2015).

Instructional Design

The relations between the various instructional guidelines discussed in this chapter are not well understood. There is evidence that some of the discussed effects are independent and, hence, affect learning outcomes additively. For example, Atkinson et al. (2003) found additive effects for interleaving by fading and prompting for self-explanations. Nevertheless, it would be naïve to assume that individual effects are all additive (i.e., the more the better). Some effects depend inherently on each other, such as example sets and self-explanations with respect to example comparisons. For example, Rittle-Johnson and Star (2009) could not encourage their learners to compare solution methods without providing sets of different example solutions. Other effects seem to interact. For example, Wouters, Paas, and van Merriënboer (2009) observed an interaction between easy-mapping in terms of a dual-mode arrangement and self-explanation prompts (i.e., no dual-mode effect under prompting condition). More theoretical and empirical analyses are necessary to better understand the interplay between the aforementioned instructional guidelines in a principled way. Such understanding would be important for adequate and parsimonious instructional design.

Practice Impact

Teacher education is a research field that is in many cases closely connected to actual practice in teacher education programs. There is strong interest in this field in videos as an instructional tool (Derry, Sherin, & Sherin, 2014). Such videos often provide models of good (and sometimes of not so good) teaching. Such videos can help connect theoretical concepts and models to classroom practice (e.g., Seidel, Blomberg, & Renkl, 2013). However, the use of video models in teacher education is not always well informed by
the instructional design guidelines, as identified in research on example-based learning and on multimedia learning (Blomberg, Renkl, Borko, & Seidel, 2013; Derry et al., 2014). Hence, applying tried-and-tested instructional guidelines, as outlined earlier in this chapter, to research on and the practice of video-based teacher education might bring about strong improvements to a very important educational field.

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