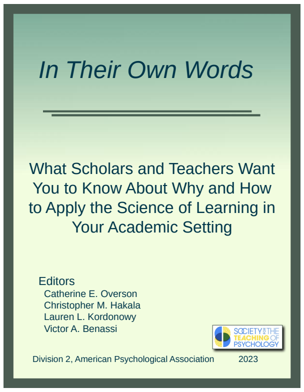

Using Worked Examples for Ill-Structured Learning Content

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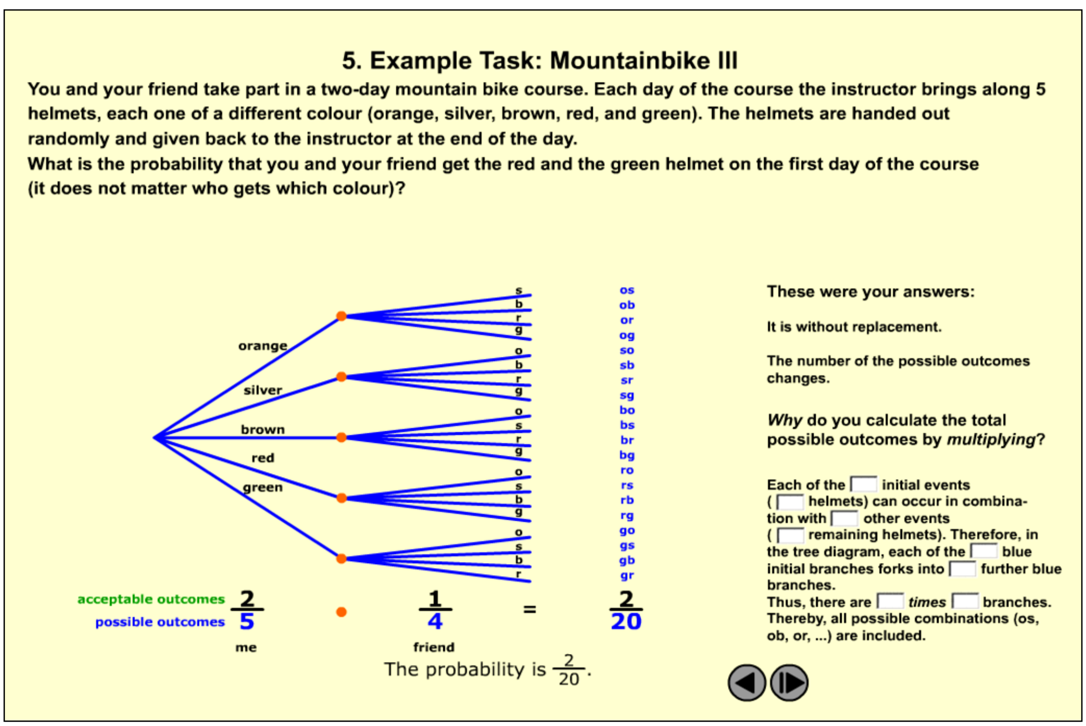
Worked Examples for Well-Structured *and* for Ill-Structured Learning Content

Worked examples show how a problem is solved. In many cases, they contain both the problem formulation and the final solution as well as the solution steps leading to the final solution. It is probably fair so say that most readers' first thoughts when reading about worked examples are associated with learning content from mathematics or physics. A typical worked example from such learning content demonstrates a mathematical solution algorithm resulting in the final solution. Actually, the worked example effect (i.e., the superior initial acquisition of cognitive skills when studying examples as compared to solving problems) was first established with such well-structured learning content (Cooper & Sweller, 1987; Sweller & Cooper, 1985; Tarmizi & Sweller, 1988). Figure 1 illustrates a worked example from well-structured learning content (Berthold & Renkl, 2009).

Figure 1

A Worked Example for Well-Structured Content (Probability)



Note. From "Instructional aids to support a conceptual understanding of multiple representations," by K. Berthold and A. Renkl, 2009, *Journal of Educational Psychology*, *101*(1), p. 71 (http://dx.doi.org/10.1037/a0013247). Copyright by the American Psychological Association. Reprinted with permission.

As the worked example effect turned out to be robust for learning to solve problems with algorithmic solution procedures (e.g., Hattie, 2009; Renkl, 2014; Sweller et al., 2019), researchers tested whether worked examples can also be used to foster initial skill acquisition when the learning content is ill-structured.[1] Ill-structured means in this case that a problem cannot be solved by an algorithmic solution procedure that, if applied correctly, leads automatically to the correct final solution. Instead, principles have to be applied that are rules of thumb (i.e., heuristics). Such heuristics help us find a solution but do not guarantee success. For example, certain moves in interdisciplinary cooperation are helpful for solving a medical-psychological diagnostic problem (e.g., Rummel et al., 2009), or certain moves help to develop a proof in mathematics (Hilbert et al., 2008). These moves, however, do not guarantee success. Figure 2 shows an excerpt from a worked example for learning to argue—another ill-structured learning content (Hefter et al., 2019).

Figure 2

Excerpt From an Argumentation Worked Example With Two Persons Discussing the Resettling of the Lynx in a German Area

Manuel:	Well, I see that differently. I believe that resettling the lynx will have negative consequences on the ecological system forest.
Alex:	Hm, I don't know.
Manuel:	But it's obvious! Resettled lynxes will lead to a collapse in the roe deer population.
Alex:	Why is that?
Manuel:	It's easy to back up. One lynx needs about 10 kg of meat a week. That's about one roe deer. Swiss studies reported that the lynx eats about 50 roe deer, 10 chamois and some small animals a year. And even if it doesn't eat all of them, the roe deer will become more timid because of fearing the lynx. In the worst-case scenario, the lynx will quite simply drive the roe deer out of the territory. Furthermore, the lynx is not the only threat for roe deer. In many forests there are ambitious hunters. If the lynx eats or drives out the roe deer, fewer will remain for the hunters. If the hunters thus intensify their hunting, the threat for the roe deer population rises.

Note. Counter-argumentation is exemplified. Depending on the learning condition in Hefter et al. (2019), this excerpt was part of a written text, of a graphic novel, or of a video. From "Effective and efficient acquisition of argumentation knowledge by self-explaining examples: Videos, texts, or graphic novels?" by M. Hefter et al., 2019, *Journal of Educational Psychology, 111*(8), p. 1400 (https://doi.org/10.1037/edu0000350). Copyright by the American Psychological Association. Reprinted with Permission

[1] In this chapter, well-structured learning content and ill-structured learning content are differentiated. Generally, it is more common to differentiate between well-structured and ill-structured domains. However, the term domain is frequently used for such areas as mathematics, physics, history, social studies etc. Note that such domains and their respective learning content do not tend to be generally well-structured or ill-structured. For example, most learning content from school mathematics is well-structured. However, finding proofs is ill-structured learning content. Hence, it makes more sense to differentiate between well-structured and ill-structure learning content in the present context.

Ill-structured learning contents, for which worked examples have been tried and tested, can be assigned to four categories:

- *Ill-structured contents within domains considered as (primarily) well-structured*: For example, arguing and proving in mathematics (e.g., Hilbert, Renkl, Kessler, & Reiss, 2008; Reiss et al., 2008), hands-on experimenting in chemistry (e.g., Koenen et al., 2017), learning by modelling in biology (e.g., Mulder et al., 2016);
- *Content from ill-structured domains*: For example, analyzing legal cases (e.g., Nievelstein et al., 2013), diagnostic competence in medicine (Stark et al., 2011), essay writing in English literature (Kyun et al., 2013), negotiating (e.g., Gentner et al., 2003), recognizing designer styles (Rourke & Sweller, 2009);
- *Cross-domain skills*: For example, arguing scientifically (e.g., Hefter et al., 2014; Schworm & Renkl 2007), interdisciplinary cooperation (e.g., Rummel et al, 2009), concept mapping as a learning strategy (e.g., Hilbert & Renkl, 2008), writing learning journals (e.g., Hübner et al., 2010; Roelle et al., 2012);
- *Ill-structured content in teacher education*: For example, teachers' decision making for managing classrooms (Cevik & Andre, 2012), teachers' assessment of students' learning strategies (e.g., Glogger-Frey et al., 2015), teachers' design of learning materials (Hilbert et al., 2008), implementing instructional design theory (e.g., Hoogveld et al., 2005), noticing and interpreting important classroom events (professional vision, e.g., Martin et al., 2020).

Theoretical Explanation of the Worked Example Effect

Why is studying worked examples more effective than solving problems in the initial acquisition of cognitive skills (e.g., learning to solve certain types of physics problems or learning to use concept mapping as a learning strategy)? The worked-example effect is typically explained as follows. If learners have just begun learning about certain rules in mathematics (e.g., the multiplication rule and the addition rule in probability), they typically have a fairly restricted understanding of these rules (often called principles in this context). If the learners then try to solve corresponding problems, they cannot rely on a genuine understanding of the relevant principles. Learning by problem solving is then usually slow and error prone (Salden et al., 2010). As learners are often cognitively overwhelmed, they might experience cognitive overload (Ashman & Sweller, this volume; Sweller et al., 2019). In their effort to find a problem solution, the learners might rely on superficial strategies (e.g., copying the solution of an earlier probability problem and adapting the numbers). Such strategies sometimes lead to correct solutions, but they do not enhance the learners' understanding of the principles or of how to apply them in problem solving (Renkl, 2014). Thus, applying such strategies can be regarded as inducing extraneous (i.e., unproductive) cognitive load. Hence, learners should first study worked examples to reach an understanding of underlying principles. Not until they do so should the learners solve problems to refine and (partly) automate their skills.

This explanation does not just apply to worked examples for well-structured contents. Imagine that learners have just heard about the principles of two-sided argumentation and should then immediately argue in that way about a complex topic; in this case also, the learners might be overwhelmed, and learning is slow and error prone. The same applies to using concept mapping as a learning strategy: if learners have just heard about the principles of effective concept mapping and they are then supposed to immediately construct a concept map about a complex topic, they might also be overwhelmed. Hence, also in the case of ill-structured content, it makes sense that the learners first gain an understanding of the principles and of how to apply them before engaging in problem solving (Renkl, 2014).

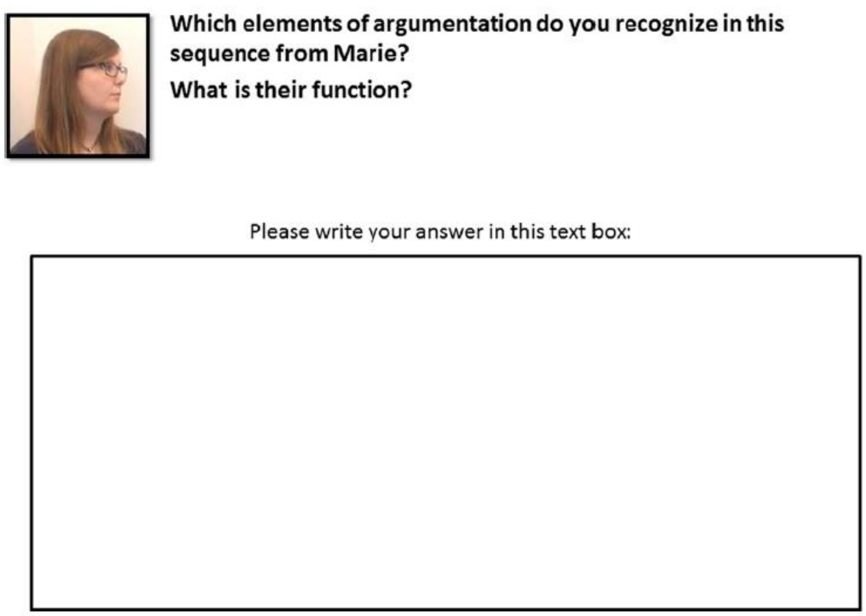
Relating Worked Examples to Principles: Self-Explanations

In the classical form of learning from worked examples, the to-be-learned principles are introduced up-front (e.g., Renkl, 2014), for example, by a short multimedia presentation or text (about 10 min). Sometimes, some test questions check whether the students have learned the basics about the principles; if the learners cannot provide correct answers, they are given additional explanations to close their knowledge gaps (e.g., Renkl, 1997). Subsequently, the learners study the worked examples, in which applying the principles is demonstrated. The learners can then relate the worked examples or parts thereof (e.g., certain utterances in an argument between two persons) to a principle (e.g., a rebuttal). Such relating is usually termed self-explanation (Chi et al., 1989; Renkl & Eitel, 2019; Rittle-Johnson et al., 2017), as the learners explain certain example features to themselves by referring to underlying principles.

However, many learners do not spontaneously self-explain (e.g., Renkl, 1997). Hence, to fully exploit the potential of example-based learning, it is advisable to foster the learners' self-explanations (Renkl, 2014; 2021). A tried-and-tested method for this purpose is to use self-explanation prompts, which are often questions or instructions to interrelate principles and worked examples. Figure 3 shows an example of a self-explanation prompt for argumentation examples (Hefter et al., 2014).

Figure 3

Self-Explanation Prompt for Video-Based Argumentation Examples



Note. From "Effects of a training intervention to foster argumentation skills while processing conflicting scientific positions," by M. Hefter et al., 2014, *Instructional Science, 42*(6), p. 936 (https://doi.org/10.1007/s11251-014-9320-y). Copyright by Springer Nature. Reprinted with Permission.

Important Specifics of Worked Examples for Ill-Structured Content

There are two typical characteristics of worked examples for ill-structured content that differ from examples for well-structured content. These characteristics should be considered when implementing learning from examples for ill-structured content.

Two Content Levels

In the vast majority of cases, worked examples for well-structured content have only one content level, which is related to the structural domain features (e.g., probability: multiplication rule and addition rule). The problem formulations, for example, in mathematics or physics word problems typically consist of simple cover stories that correspond to the examples' surface features. In the case of worked examples for ill-structured content, there are typically two "substantial" content levels that learners have to process. For example, when students learn about two-sided argumentation, they are given examples showing argumentation about a complex and controversial topic such as global warming and forest dieback (e.g., Hefter et al., 2014). Another example is illustrated by student teachers learning how to notice and interpret classroom events such as student-centered teacher behaviors in a classroom video; the instruction presented in the video is about learning content, as specified in the curriculum, such as the human circulatory system (Martin et al., 2020). Renkl et al. (2009) differentiated these levels into the *learning domain* (e.g., how to structure an argument; how to notice and interpret certain types of teacher behaviors) and the *exemplifying domain* (i.e., global warming and forest dieback; human circulatory system). The learners have to integrate information from both content levels. For example, they will not notice that a teacher in a video example is reacting to a student's misconception if they do not closely follow the conversation about the human circulatory system.

This distinction between content levels loosely relates to the differentiation between structural features (i.e., solution-relevant features) and surface features (e.g., cover story, objects, numbers) typically used in research on worked examples for well-structured content. For example, in the case of mathematical word problems the surface features correspond to a “lean description of some situation” (Greer, 1997, p. 297). Although, some learners might also have problems understanding the description of a relatively simple situation, the difficulty in understanding exemplifying domains in the case of worked examples for ill-structures content is usually much greater, and learners also need to understand the exemplifying domain as just illustrated by the example case of a teacher reacting to a student's misconception. In other words, comprehension difficulties in the exemplifying domain can hinder learners from seeing how the learning domain's principles are instantiated.

The need to process two complex content levels has two important implications when designing worked examples for ill-structured content. First, the exemplifying domain should not be difficult, otherwise some learners might be overwhelmed by the demand to process both content levels. In fact, learners with low prior knowledge in the exemplifying domain were found to obtain poor learning outcomes in the learning domain (Hilbert et al., 2004; Hilbert, Renkl, Kessler, & Reiss, 2008). If, for some reason, a difficult and challenging exemplifying domain is chosen, pre-training those contents might be advisable, that is, teaching the exemplifying domain's basics before providing the worked examples to teach the learning domain (e.g., Clarke et al., 2005). Second, the processing support should focus the learners' attention primarily on the learning domain, not on the exemplifying domain. For example, when learning about two-sided argumentation, prompts directing the learners' attention primarily to the exemplifying domain (e.g., climate change and forest dieback) hamper knowledge acquisition in the learning domain (e.g., Schworm & Renkl, 2007). Similarly, requiring learners to fill-in gaps in geometric expressions (exemplifying domain) was detrimental for learning to prove (learning domain; Hilbert et al., 2008).

Complex Skills as Learning Goals

Typical worked examples from mathematics teach circumscribed domain-specific skills, for example, learning to apply the complementary rule, the multiplication rule, and the addition rule to probability problems (e.g., Atkinson et al., 2003) or determining angles in triangle geometry (Ginns et al., 2016). Worked examples for ill-structured learning content usually teach more complex skills that develop over longer periods such as learning to prove in mathematics (e.g., Reiss et al., 2008), learning to argue in a two-sided way (e.g., Hefter et al., 2014; Schworm & Renkl, 2007), or analyzing legal cases (e.g., Nievelstein et al., 2013). Hence, the example-based lessons tried and tested in corresponding studies could in most cases "just" be regarded as kick-off interventions on the way to acquiring such complex skills. Hence, they show practitioners how a good starting point might look. However, the skills will have to be further expanded upon in subsequent lessons.

Three Illustrative Applications of Worked Examples for Ill-Structured Learning Content

To flesh out the preceding discussion of learning ill-structured contents from worked examples, three rather heterogeneous cases will be presented in some depth: Two-sided argumentation (cross-domain skill), mathematical proof and argumentation (ill-structured content from a domain usually regarded as well-structured), and teachers' professional vision (teacher education). These cases are discussed in a parallel form to clarify how the key elements of learning ill-structured content from worked examples appeared in the corresponding studies.

Two-Sided Argumentation

Berthold, Hefter, Renkl and colleagues conducted several studies in which video-based worked-examples were used to foster two-sided argumentation (Hefter et al., 2014, 2018, 2019; Schworm & Renkl, 2007). The students should learn not only to consider one perspective when reflecting about complex issues such as climate change or gene-modified food, but also to ponder the pros and cons of different perspectives.

Learning Domain

The goal was to foster the skills of high-school students and, in one study of student teachers, in two-sided argumentation as a key to developing deep understanding of complex topics, in particular, in science (e.g., Kuhn, 2001, 2010). The authors largely followed the argumentation model by Kuhn (1991). The first (heuristic) step in arguing well is to support one's own position (e.g., perspective or theory) with strong arguments (e.g., by referring to scientific evidence rather than to an example from one's own life). The second step comes up with an alternative theory that is also supported by some evidence. The third step generates counterarguments against one's own position. The fourth step is a synthesis based on carefully evaluating the strengths of all the arguments and counterarguments stated (which somewhat deviates from Kuhn's model; e.g., Kuhn, 1991). In some studies (e.g., Hefter et al., 2019), six (heuristic) steps were differentiated (i.e., theory, genuine evidence, alternative theory, counterargument, rebuttal, and synthesis). Note that the focus was not on fostering argumentation when debating with others, but rather on argumentative thinking (i.e., when thinking about complex topics: supporting one's own position, considering an alternative position or theory, etc.).

Fostering such a cross-domain skill is a demanding challenge for educators, and it must be pursued as a long term-goal. Such a skill is, as already mentioned, important for learning about complex topics (e.g., Iordanou et al., 2019). Beyond this aspect, such skills have probably become even more necessary in recent years, as we seem to have entered a post-truth era in which there are demands for educational responses to equip students with the skills to critically evaluate misinformation, "alternative truths," or conspiracy theories (e.g., Barzilai & Chinn, 2020).

Exemplifying Domains

Berthold, Hefter, Renkl and colleagues have used various exemplifying domains in which the worked examples revealed two-sided argumentation: stem-cell research, achievement differences between girls and boys in mathematics and science (Schworm & Renkl, 2007), resettling the lynx in a specific forest area, or global warming and forest dieback (Hefter et al., 2014, 2018, 2019).

Introducing the Principles

The four or six argumentation steps described above were the principles to be exemplified in the videos. They were introduced by a short text-based presentation on a computer monitor (e.g., Hefter et al., 2014, 2019). To introduce the steps, an initial example was already used (e.g., the extinction of the dinosaurs).

The Worked Examples

The worked examples consisted usually of videos showing two students arguing about complex topics, such as resettling the lynx in a specific forest area or global warming and forest dieback (Hefter et al., 2014, 2018). The two students held conflicting positions (for an excerpt, see Figure 2). Hefter et al. (2019) also successfully applied text-based worked examples (see Figure 2) as well as graphic-novel versions of the videos. That is, screenshots from the videos were taken and bubbles with the text were added (see Figure 4).

Figure 4

Screenshot from a Graphic Novel Version of a Worked Examples on Argumentation

Note. From "Effective and efficient acquisition of argumentation knowledge by self-explaining examples: Videos, texts, or graphic novels?" by M. Hefter et al., 2019, *Journal of Educational Psychology, 111*(8), p. 1401 (https://doi.org/10.1037/edu0000350). Copyright by the American Psychological Association. Reprinted with permission.

Eliciting Self-Explanations

Self-explanation prompts were employed to foster the processing of the worked examples in terms of the to-be-learned argumentation steps (Schworm & Renkl, 2007; Hefter et al., 2014, 2018, 2019). Such a prompt is illustrated in Figure 3. The prompt supports the learners to attend not merely to the exemplifying domain (e.g., resettling the lynx), which may be more salient when listening to dialogs, but primarily to the underlying argumentative structure.

Further Practical Considerations

Video-based worked-out examples might appear more authentic at first glance. However, Hefter et al. (2019) detected no advantage for such examples in terms of learning outcomes, as compared to examples in a text format or a graphic-novel format. Rather, learners required less learning time from the written and from the graphic-novel formats, meaning that such examples were more efficient than video examples. Another advantage is that the graphic-novel format and the written format in particular are easier to produce.

Mathematical Argumentation and Proof

Reiss, Renkl and colleagues (e.g., Reiss & Renkl 2002; Hilbert, Renkl, Kessler, & Reiss, 2008; Reiss et al., 2008) developed worked examples for teaching the skills of mathematical argumentation to high-school (or first-year university) students as a prerequisite for finding proofs.

Learning Domain

The goal was to foster students' skills of mathematical argumentation as a basis for later proof finding. More specifically, the students learned about a sequence of heuristic steps for proof finding, which were taken from Boero (1999) in a slightly modified version. The students learned the following sequence: exploring a problem situation to formulate an initial conjecture (*production of a conjecture*), formulating the initial conjecture as a clear statement (*formulation of a statement*), exploring their conjecture by identifying appropriate arguments (*exploration of the conjecture*), and finally selecting and combining arguments in a coherent deductive chain (*selection and combination of coherent arguments in a deductive chain*).

As proof is central to mathematics, it is a central goal of mathematics education in schools, namely that students develop at least some basic understanding of the concept of proof as well as basic skills in handling proofs (e.g., constructing, comprehending, validating; Sporn et al., 2021). However, many students have fairly little understanding of proofs and deficient skills at the end of high school and when entering university education (e.g., Sporn et al., 2021). Hence, it is important and demanding to foster students' proving skills and their basis in mathematical argumentation.

Exemplifying Domain

The exemplifying domain was geometry. For example, students had to prove that opposing sides and opposing angles in a parallelogram have the same size.

Introducing the Principles

The details of the introduction differed somewhat between studies. In a classroom study with 8th graders (Reiss et al., 2008), teachers provided their regular introductory instruction ("business as usual") before the students were given worked examples.

The Worked Examples

The worked examples were substantially longer than typical worked examples (i.e., 10 or even more pages). The examples included two or even three fictitious students who went through the four phases of a mathematical argumentation process (Boero, 1999). The fictitious students discussed their ideas and always spoke their thoughts out loud, which can be considered as a type of cognitive model. A reason to use student models was their similarity to the high-school students, which helps the learners to identify with fictitious students, thus enhancing their self-efficacy (e.g., Bandura, 1986, 1971; for an example see the Appendix of Reiss et al., 2008). Such an example began as follows:

The Problem:

> Nina and Tom have drawn and measured parallelograms. In doing so, they noticed that opposing sides were always of equal length. Moreover, opposing angles were always of equal size.
>
> > ***Tom***: ''We measured so many parallelograms: We have drawn all kinds of quadrangles, and always we recognized that the opposing sides were of equal length and opposing angles were of equal size. I think, it has to be like this!''
> >
> > ***Nina***: ''I think you are right, but I don't know a reason. Maybe by chance, we have only drawn parallelograms for which the statement is correct? We cannot measure the angles and sides exactly. Perhaps they were only approximately of the same size.''
> >
> > ***Tom***: ''So let's try to prove our assumption like mathematicians would do!''
>
> Tom and Nina try to prove the following mathematical proposition:
>
> > ''In a parallelogram opposing sides are of equal length and opposing angles are commensurate!'' In the following we have a look at how they solved the mathematical problem. Please read their solution …" (Reiss et al., 2008, pp. 463-464)

Eliciting Self-Explanations

Various studies on such worked examples employed somewhat different self-explanation prompts. Hilbert, et al. (2008) used prompts that were most directly related to the sequence of heuristics to be learned, and their prompts proved to be effective in an experimental test. When going through the worked examples, the learners answered four two-fold self-explanation prompts. First, the learners were asked in a multiple-choice format in which phase the two fictitious students had been in the preceding section: (1) production of a conjecture, (2) formulation of a statement, (3) exploration of the conjecture, and (4) selection and combination of coherent arguments in a deductive chain. Second, the learners had to write a brief justification for their choice.

Further Practical Considerations

A measure to deepen the active processing of worked examples used in part of the studies (e.g., Reiss et al., 2008) was inserted gaps in the geometry information that the learners had to filled in (completion requirements). However, Hilbert et al. (2008) found that such gaps, especially when combined with self-explanation prompts, have detrimental effects. Obviously, they direct the learners' attention away from the learning domain of proving to the exemplifying domain of geometry. Such gaps should therefore be avoided. Recent studies combined heuristic examples with (scripted or unscripted) cooperation (e.g., Kollar et al., 2014; Schwaighofer et al., 2017). However, it is not yet clear that studying worked examples on mathematical argumentation cooperatively rather than individually is more effective. Hence, an individual learning approach might be advisable in this context, as it is easier to implement.

Student Teachers' Professional Vision

Farrell, Martin, and colleagues (Farrell et al., 2022; Martin et al., 2022) investigated the effects of an example-based 90-minute seminar session as a kick-off intervention to foster student teachers' skills in noticing and interpreting important classroom events in terms of theoretical concepts (professional vision). More specifically, the student teachers should learn to notice and interpret example cases of teacher-centered or student-centered tutoring behaviors and corresponding student reactions.

Learning Domain

The goal was to foster student teachers' *professional visions skills* in the area of tutoring situations (e.g., teachers working with a group of four students during a phase of group work). Professional vision (skills) means that the student teachers notice relevant events, here in videos, and that they interpret these events by relying on their theoretical knowledge (Santagata et al., 2007; van Es & Sherin, 2002). More specifically, the student teachers should learn to notice and interpret teacher-centered tutoring behaviors and student-centered tutoring behaviors, as well as the corresponding student reactions. The student teachers should also learn that one of the major advantages of tutoring situations, that is, the possibility to tailor instruction to students' specific learning prerequisites, is more fully exploited if the teachers primarily show student-centered behaviors (e.g., having the students explain their potentially misconceived concepts instead of simply teaching the correct concept).

Teaching such skills is nothing trivial. There is ample evidence that student teachers seldom interpret teacher and student behaviors on the basis of theory. Instead, they often judge prematurely whether the noticed events were "good" or "bad" without substantive justification (e.g., van Es & Sherin, 2002; Seidel & Stürmer, 2014), and they oversimplify learning and teaching issues (Jacobs et al., 2010). The development of sophisticated professional vision skills is a major challenge in teacher education (e.g., Stürmer et al., 2016).

Exemplifying Domain

The exemplifying domain was instruction on the human circulatory system, which is part of the biology curriculum at the secondary level. Note that high-school students – also those depicted in the video-based worked examples – have several misconceptions regarding the circulatory system. For example, many students think of the circulatory system as a single-loop instead of a double-loop system.

Introducing the Principles

The principles exemplified in the videos were explained in introductory texts (e.g., Martin et al., 2020). Depending on the condition, there was an introductory text (about 1000 words) with a biology-education perspective or with an educational psychology perspective on tutoring situations. A control group was given "just" a text with general guidelines for observing classroom videos. We instructed the participants to read the introductory text carefully and to remember the information for its subsequent application in a video analysis.

The Worked Examples

The worked examples were presented in videos showing teacher-centered and student-centered tutoring behaviors as well the corresponding student reactions. The videos lasted 7 to 10 minutes and showed, for example, a discussion about differences between the students’ drawings of the circulatory system and a scientific diagram. The videos were staged (scripted) and enacted by biology teachers and four students who had volunteered to make such videos recordings. However, the individual tutoring behaviors and student reactions were taken from authentic videos. The staging of videos made them more condensed in the sense that the observing student teachers could see relatively many teacher-centered and students-centered behaviors in a short time period (note that the videos contained both types of behaviors, as did the authentic videos). For learning, the student teachers watched two video scenarios.

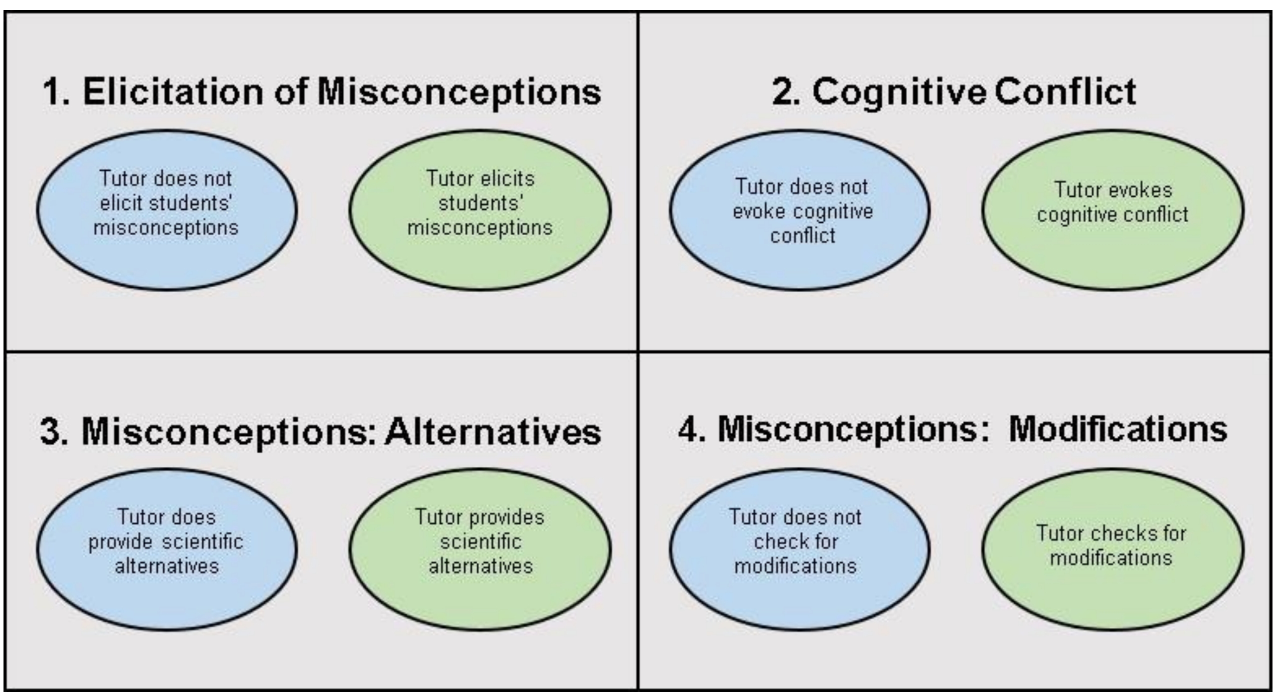
Eliciting Self-Explanations

The student teachers marked events they considered relevant for teaching and learning by pressing a button on the keyboard (noticing). After each video, they commented on some of their marked events (interpreting); this activity is regarded as self-explanation. In addition, the student teachers rated the videos on professional-vision rating scales, for example, the extent to which tutors had elicited students' misconceptions.

Martin et al. (2022) further supported self-explanations by providing a figure displaying important concepts from the introductory text such as eliciting students' misconceptions (see Figure 5). After watching a video or, in the case of segmented videos, after each video segment, the student teachers could click on the concepts perceived as relevant to the previous video, and they could continue to interpret the relevant events

Figure 5

Pre-Structured Self-Explanation Prompts Presented Within an Interactive Figure Displaying the Principles Outlined in the Introductory Text



Note. Used in the study by Martin et al. (2022).

Further Practical Considerations

In Martin et al. (2022), the videos were cut into smaller segments lasting 3 to 4 minutes. Note that video provides transient information so that student teachers can easily overlook important information when distracted by irrelevant information (e.g., the teacher has a peculiar accent) or when sticking to relevant information (e.g., thinking a bit longer about an important event). Segmenting can reduce the problem of transient information. Noticing and interpreting worked best with segmented videos (in comparison to unsegmented videos), especially when combined with pre-structured self-explanation prompts. A limitation here was, however, that no transfer of this good performance occurred to new videos without segmenting and self-explanation prompts. Longer training with segmented video and self-explanation prompts is probably necessary (note: there was just one seminar session in the studies of Martin and colleagues).

Guidelines for Implementing Learning From Worked Examples for Ill-Structured Contents

Writing a comprehensive guide to implementing learning from worked examples for ill-structured contents would take a whole book. The goal of this section is to provide some guidelines as a starter. If practitioners (i.e., teachers or instructional designers) aim to dive deeper into this topic, they might want to read additional reviews (e.g., Renkl, 2014, 2021; Renkl et al., 2009; Mayer, 2021; van Gog et al., 2019) and original studies for models (see the cited studies in this chapter). In addition, the scientific literature does not usually answer all the detailed questions that arise when implementing an instructional model in practice (e.g., Biesta, 2007). Hence, practitioners should also rely on other knowledge resources such as their experiential knowledge about what works in their specific context (i.e., subject matter, grade level, school culture, their students' achievement level, classroom composition, etc.) when implementing learning from worked examples.

Suggested Steps to Designing Learning From Worked Examples for Ill-Structured Content:

1. **Identify the To-Be-Learned Principles**: The principle(s) to-be-taught should be determined. They may be heuristic steps in solving an ill-defined problem or important features a good case should have (e.g., a good concept map). These principles might be taken from theoretical models (e.g., argumentation model), from empirical research (e.g., findings on effective concept mapping), or the heuristics common to or recommended in certain subjects (e.g., steps for solving mathematical word problems). This step is essential because it defines the learning domain and, thereby, determines what the worked examples should primarily demonstrate.
2. **Design a Short Presentation of the Principles:** The goal of this short presentation (e.g., a text, a multimedia presentation, or a classroom presentation) is not that the learners acquire full understanding of the principles and their application—that goal should be pursued later during example study. However, the point of the goal is that learners should acquire factual knowledge of the principles and some rudimentary understanding. For this purpose, an initial easy example can be included in this presentation.

   As the learners should be able to recall the principles when later studying worked examples, the practitioner might also pose questions to check whether the learners can remember the principles. If there are knowledge gaps, re-teaching should close such gaps.
3. **Design Worked Examples:** As learning from worked examples involves the use of multiple examples, several examples need to be constructed that clearly represent cases of the application of the to-be-learned principles (learning domain). It might not be necessary to construct fancy worked examples, for example, in form of high-quality videos (e.g., with professional speakers). In most cases, written worked examples may suffice or even be preferable (e.g., Hefter et al., 2019), though they might not look very inviting at first glance.

Note that videos also have disadvantages such as delivering transient information. Of course, there might be good reasons to use video in some cases (e.g., presenting authentic classroom situations to student teachers).

It is advisable to use exemplifying domains which are relatively easy to understand. Otherwise, a pre-training session on this content will be necessary. Thereby, it is avoided that the learners must devote so much of their cognitive capacity when trying to understand the exemplifying domain that they become distracted from the learning domain. Another potential pitfall is to select an exemplifying domain that is a very hot topic (e.g., mandatory COVID vaccination). Such a topic might engage the learners both cognitively and emotionally to a dysfunctional degree. In such a case, the exemplifying domain might also distract from the learning domain.

4. **Add Self-Explanation Prompts to the Worked Examples:** To fully exploit the potential of learning from worked examples and to keep learners from primarily focusing on the exemplifying domain, self-explanation prompts can be added. These prompts ask learners to relate example features to the underlying principles. Self-explanation prompts vary on a dimension from open (e.g., "Explain which principle applies here") to pre-structured (e.g., "Select from the menu the principle that applies here"; a menu lists potentially relevant principles; see also Figure 5 for a pre-structured prompt). Particularly in the first worked examples, it is probably better to use pre-structured prompts (e.g., Renkl & Eitel, 2019; Rittle-Johnson et al., 2017); later on, more open prompts might be employed.
5. **Consider Multimedia Principles**: If multimedia design principles (e.g., Mayer, 2021; Mayer, this volume) are violated, learning from worked examples might be less effective or even lose entirely its advantage over learning by problem solving (e.g., Tarmizi & Sweller, 1988; Renkl, 2021). For example, if multiple representations such as text and diagrams are used (e.g., worked examples for learning concept mapping contain written explanations and well-designed concept maps) or if fleeting information is presented (e.g., in videos or animations), the processing demands might overwhelm at least some learners. Such learners need support or materials that are easier to process (e.g., text instead of video). It is beyond the scope of this chapter to discuss multimedia design principles; the interested reader might refer to Clark and Mayer (2016), Mayer (2021; this volume), or Renkl (2021).
6. **Continue With the Learning Domain:** As already mentioned, learners studying worked examples for ill-structured contents are often expected to acquire complex and difficult skills. Hence, providing an initial unit with an introduction to the principles and a set of corresponding worked examples might be an excellent kick-off intervention on the way to acquiring such complex skills—but it is just a start. It is necessary that practitioners continue to promote such skills in subsequent instruction, initially via additional worked examples and later also by giving their learners growing opportunities to practice their skills (e.g., Renkl, 2014; 2021).

A Final Word

To those who give the aforementioned approach a try: Considering my own experience as a university teacher, the very first attempts to implement an instructional idea are rarely entirely satisfying. However, they are an excellent starting point to determine what actually works and what needs to be improved. Good luck with your first attempt and for fine-tuning your approach.

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