Learning by Solved Example Problems: Instructional Explanations Reduce Self-Explanation Activity

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Abstract

Learning from worked-out examples is of major importance for initial skill acquisition in well-structured domains. In addition, research has provided knowledge in regards to structuring worked-out examples and how to effectively combine self-explanation activity and instructional explanations. The goal of the present project was to develop a computer-based learning environment in which teachers can learn how to use worked-out examples. Examples of favorably and unfavorably designed worked-out examples were the primary source of information for the teachers. The examples (of worked-out examples) were not in themselves worked-out examples if one views them from a design perspective as the (design) solution steps were not given. We have labeled this type of examples "solved example problems." We investigated to what extent learning from such solved example problems could be fostered by self-explanation prompts and by providing instructional explanations. The results of our 2x2 design (80 student teachers) showed that prompting self-explanations in particular had favorable effects. Hence, self-explanations fostered learning not only from worked-out examples but also from solved example problems. Supplementary instructional explanations only partially enhanced learning and at times they were even detrimental.

Introduction

This study applies the results of cognitive science research (i.e., worked-out example and self-explanation research) to the design of a computer-based learning environment. An empirical study about this learning environment, in turn, contributes to the research on example-based learning and self-explanations.

Learning from worked-out examples is of major importance for the acquisition of cognitive skills in well-structured domains such as mathematics or physics (for an overview see Atkinson, Derry, Renkl, & Wortham, 2000). However, worked-out examples do not guarantee effective learning. One moderating factor is the learner's self-explanation activity. Only when a learner actively self-explains the rationale of the worked-out solutions to her/himself will s/he gain an understanding of the solution procedures. Another factor is the provision of instructional explanations. In the study presented below, teacher students learned in an example-based computer learning environment how to effectively structure and combine worked-out examples. It was intended to foster their learning by the employment of self-explanation prompts and by supplementary instructional explanations.

Learning by Worked-Out Examples

Worked-out examples consist of a problem, solution steps and the complete solution to the problem. Usually they can be found in mathematics and physics schoolbooks. In most cases, a principle or law is introduced in the beginning followed by a worked-out example. The worked-out example shows how the principle can be applied to problem solving. Then, problems to be solved by the students are given.

Learning by worked-out examples is not meant to refer to the short learning phase between the introduction of a principle and problem-solving. It means, instead, that the example phase is prolonged. Several studies have shown that such example-based learning is more effective for skill acquisition than the standard procedure of studying just one example and then solving problems (for an overview see Sweller, van Merriënboer, & Paas, 1998).

Of course, the use of worked-out examples do not guarantee effective learning. Learning outcomes are influenced mainly by (1) the learner's self-explanation activity and the provided instructional explanations and (2) how the learning materials (examples and problems) are structured (cf. Atkinson et al., 2000). These two aspects are discussed in the following sections.

Self-Explanations and Instructional Explanations

The extent to which learners benefit from the study of worked-out examples depends on how well they explain the rationale of the presented solutions to themselves ("self-explanation effect", Chi et al., 1989; Renkl, 1997; Renkl, Stark, Gruber, & Mandl, 1998). It is especially useful to make the "meaning" of specific operations explicit by reifying the relationship between (sub-)

goals and operators or with the principles underlying a specific operation.

Whereas self-explanations are of major importance, research has shown that the effects of instructional explanations are often disappointing (e.g., Brown & Kane, 1988; Chi, 1996). It seems to be more effective to prompt self-explanations than to offer instructional explanations. On the other hand, it has to be taken into account that relying solely on self-explanations also has several disadvantages. For example, at times the learner is not able to self-explain a specific solution step or the given self-explanations are incorrect.

Renkl (in press) developed a set of instructional principles to support the spontaneous self-explanation activity by providing instructional explanations. Two central principles are (1) the priority of self-explanations (instructional explanations should just be used as type of support) and (2) the furnishing of instructional explanations on learner demand. The study of Renkl (in press) showed that such instructional explanations heightened the average learning outcomes.

However, instructional explanations may not only have positive effects. Due to their feedback functions, a specific problem can occur (e.g., Kulhavy, 1977). If feedback containing the correct answer (here: the explanation) is easily available, learners typically reduce their effort in attempting to find the answer on their own. They tend to look up the right answer instead of coming up with the answer themselves – which reduces learning outcomes. Thus, the provision of instructional explanations may reduce self-explanation activities. Aleven and Koedinger (2000) found, in the context of computer-based learning, that in more than 80% of the cases their learners did not use available help which additionally required self-explanation activity. The learners asked directly for the help which contained the final solution.

In summary, self-explanations are of major importance when learning from worked-out examples. Instructional explanations can foster learning but often they do not. What is left open is the question as to what extent the findings on (self-) explanation can be generalized to non-mathematized content areas.

Design of Worked-out Examples

Researchers (e.g., Catrambone, 1996; Mwangi & Sweller, 1998) have suggested that the design of worked-out examples plays a critical role in their effectiveness (intra-example features). For example, featuring sub-goals prominently fosters learning outcomes (Catrambone, 1996). In the present study, we focused on the so-called *integrated format*: Examples are constructed which integrate all sources of information into one source (e.g., diagrams and text). Splitting learners' attention across multiple, non-integrated informational sources causes irrelevant cognitive load and impairs learning (Mwangi & Sweller, 1998; Ward & Sweller 1990).

Beyond the structure of single worked-out examples the combination of multiple examples is of significance for learning outcomes (inter-example features). In general, multiple examples that contain different surface features (e.g. figures, objects) should be used. This aids the learner's ability to recognize the common underlying structure when asked to compare examples.

Often there are two or more different structures to be learned. It is important to emphasize the structural aspects by using very similar surface features for different problem types. Learners frequently do not recognize the difference of the underlying structure because they concentrate on the similarity of the surface features. Therefore, they often choose the wrong solution. Thus, when dealing with different but interrelated problem types, multiple examples should be combined in such a way that the relevant structural features are apparent to the learner (*structure-emphasized example set*). This can be achieved, as stated above, by using different surface features within one problem type and similar surface features between the different problem types (Quilici & Mayer, 1996).

Of course, there are many other example features which influence the effectiveness of learning from worked-out examples, but in the first module of our computer-based learning environment, we implemented only two features: the integrated format and the structure-emphasized example set.

Research questions

Taking into account the current research on learning from worked-out examples, two important questions can be formulated:

(1) How can we teach teachers the knowledge about the effective use of worked-out examples in their classroom? To reach this goal means to bridge research findings into practice and to improve the quality of instruction.

(2) Do self-explanations and additional instructional explanations foster learning when learning from solved example problems, that is, examples that do not provide solution steps but only the problem and the final solution? Such a solved example problem would be, for example, a well-written essay (literature) or the picture of an intriguing mask (arts). So far it remains an open question as to what extent the results of the worked-out example research, which were mainly obtained within the context of learning mathematics and physics, can be transferred to learning by solved example problems in other topic areas.

For addressing the first question we have developed an initial module for a computer-based learning environment. It is the first part of a future web-based learning environment in which teachers can learn how to use worked-out examples in their classrooms. Due to its intended net-based use, not only "objective" learning outcomes were of interest but also the program's acceptance and the perceived learning results. Those

aspects are of major importance when offering a facultative learning opportunity to practitioners. Acceptance is the basis of the usage of the program itself whereas the perceived results are a predictor for its implementation in classrooms.

In this module, future teachers learn about the design of worked-out examples by studying cases of well and poorly designed worked-out examples. It is important to note that the design of worked-out examples is not an algorithmic process with specific solution steps. Therefore, the examples of the program are, as viewed from the teacher's perspective, not worked-out examples (they do not contain any solution steps) but instead solved example problems (there is simply the problem and its solution) (see Fig. 1).
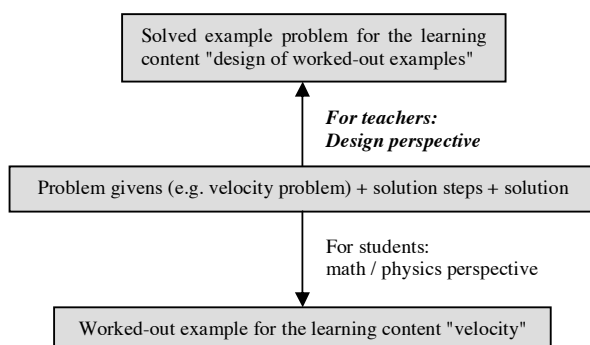

Figure 1: Contents of the learning program from different perspectives

The second research question of this study addresses the effectiveness of self-explanations and instructional explanations when learning by solved example problems: Do self-explanation prompts and additional instructional explanations upon learner demand foster learning?

The following specific research questions were addressed:
1. Is there – as expected – a positive effect of prompting self-explanations on learning outcomes?
2. Is there a positive effect of providing instructional explanations?
3. Do the two instructional means combine additively or non-additively?
4. Do the different instructional treatments influence acceptance and perceived leaning outcomes?

Methods

Sample and Design

80 student teachers from two different colleges volunteered to take part in this study (mean age: 22.3 years; 52 female and 28 male participants). One part of the participants were future teachers in German low-track and medium-track schools ($n = 47$), the other part were future teachers in high-track schools ($n = 33$). The participants were randomly assigned to the four experimental conditions of a 2x2-factorial design ($n = 20$ in each group). In the experiment, the participants learned in a computer-based learning environment how to effectively design worked-out examples by studying solved example problems (factor 1: prompting self-explanations [with and without], factor 2: instructional explanations [with and without]). In the analysis of the written self-explanations (reactions to the prompts), 6 participants are missing due to technical problems (3 per cell). Technical problems also led to 4 missing values with respect to time-on-task which was recorded as a control variable.

Learning Environment

The program contained a short introduction about learning with worked-out examples. Afterwards examples of worked-out examples or sets of examples were displayed. They were taken from the domains of geometry and physics.
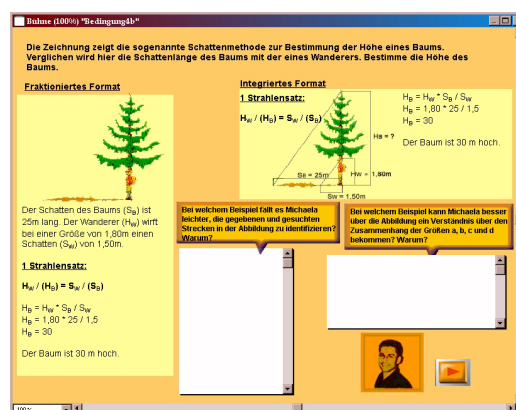

Figure 2: Screenshot of the learning environment

Figure 2 shows a screenshot of the learning environment with a solved example problem with an integrated format. Two worked-out examples were presented to the participants—one required the mapping of different sources of information (graphic, calculation, and text – left side) whereas the other was designed in an integrated format (right side). The self-explanation prompts asked the learners to comment on why one of these two worked-out examples was more favorable. Self-explanations had to be provided to all 13 prompts but their extensiveness (number of elaborations) was self-regulated by the learner. The provided instructional explanations were—in a sense—answers to the self-explanation prompts. They were presented verbally when the learners clicked on a button. The button contained a picture of an expert teacher introduced earlier in the program (see Fig. 2). A "text"-button, which appeared after the acoustic presentation, enabled the learner to view a written explanation. The instructional explanations were

demanded 4.13 times on average (*SD* = 3.31). The frequency of demands did not correlate with learning outcomes. Therefore, this variable was not further considered.

Procedure

The participants worked in individual sessions of approximately 3 hours. In order to provide basic knowledge to allow the participants to be able to understand the solved example problems, an instructional text containing the basic principles of the worked-out example design was given to the participants. Afterwards they studied several solved example problems dealing with an integrated format and structure-emphasized example set in the domain of geometry and physics. The different domains were chosen to foster the transfer of the acquired knowledge. All participants were instructed to think aloud during this period in order to assess (oral) self-explanations (these data have not yet been analyzed). The group with prompted self-explanations had to write down their explanations in note-boxes. During the study of examples, the time spent on different pages of the learning program was registered. After studying the solved example problems, the participants worked on the post-test (learning outcomes). Lastly, the participants filled out a questionnaire regarding the perceived usefulness of the program.

Instruments

Post-test: Assessment of the Learning Outcomes. The first part of our post-test consisted of selection tasks. The participants had to choose one of several given worked-out examples (integrated format) or they had to combine four examples to a structure-emphasized example set. The domains used were geometry, physics (near transfer), and arithmetic (far transfer). For near and far transfer there were three tasks with increasing complexity. Depending on the complexity of the task 1, 4 or 6 points could be achieved (selection part: maximum of 22 points). The second part was a generation task: The participant had to create a structure-emphasized example set in an integrated format. The quality of this task solution was rated by three raters according to specified criteria (e.g., using integrated format in all examples). An entirely correct solution was awarded with 12 points.

Questionnaire. Included in the questionnaire were demographic questions as well as questions concerning the acceptance of the learning environment and the perceived learning results. The items were to be answered on a rating scale from 1 to 6. For the acceptance scale (19 items; e.g., "The content of the program was easy to understand."), we obtained a Cronbach's α of .86. There were four items that assessed the perceived learning results (e.g., "How would you judge your current knowledge about worked-out examples?"; Cronbach's α: .72).

Written Self-Explanations. In the learning program, the learners in the self-explanation groups were prompted 13 times. The written self-explanations were analyzed using a specifically developed coding system. The main categories were as follows:

(1) *Connection between the design principles of worked-out examples and the solved example problem presented in the program* (e.g., "The variables are written next to the lines, therefore there will be less mapping problems.").

(2) *Linkage to the learning-goals* (integrated format or structure-emphasized example set) (e.g., "A different surface does not automatically require a different solution method.").

(3) *Mathematical content of the solved example problems* (e.g., "In both examples I have to determine the speed.").

(4) "*Side-aspects*" These remarks were correct but did not refer to the learning goals of the program (knowledge about integrated format or structure-emphasized example set) (e.g., "… provided that the second [example in integrated format; comment by the authors] could be drawn clearer.").

(5) *Metacognition* (e.g., "I would have solved the problem in the same way.").

The written reactions to the self-explanation prompts were segmented with the coding categories in mind. Often more than just one elaboration (category) was coded in a reaction to a prompt. The coding categories were distinct and there were no inclusions of segments. A few utterances did not fall into any of the categories (e.g., statements about specifics of the learning program), so they were not taken into account.

We aggregated the codings in two respects. First, all categories were summed up together to an overall score of elaboration activity. The single categories occurred relatively infrequently so that corresponding scores would have not been reliable. Second, the elaborations in reaction to the 13 prompts were aggregated.

Results

Pre-Analyses

In the post-test, a maximum of 34 points could be achieved (*M* = 23.20; *SD* = 5.67). The two subtests (selection and generation) were summarized, due to their similar result patterns and their positive correlation ($r = .31$; $p < .05$).

The post-test correlated significantly with the perceived learning results ($r = .41$; $p < .05$). It did not significantly co-vary with the acceptance scale ($r = .06$; $p > .10$). There was a significant correlation between the acceptance and perceived learning results ($r = .51$; $p < .05$).

The amount of elaborations in the written self-explanations was found to be an important predictor of the learning outcomes ($r = .55$; $p < .05$). There was no significant influence of time-on-task on learning outcomes ($r = .19$; $p > .10$); even in the single subgroups there were no significant relationships between time-on-task and learning outcomes. This pattern in the results indicates that it was not primarily the quantitative aspect of learning (learning time), but the qualitative aspect (elaborations) which influenced learning outcomes. Table 1 summarizes the descriptive results of time-on-task, written self-explanations, acceptance, perceived usefulness, and learning outcomes (posttest).

Effects of Self-Explanation Prompts and Instructional Explanations

In order to determine the effects of our experimental variations, we performed an ANCOVA controlling for the type of student teachers. This variable significantly influenced learning outcomes (low- and medium-track teachers: $M = 22.05$, $SD = 5.76$; high-track teacher $M = 24.83$, $SD = 5.18$; $t(78) = 2.21$; $p < .05$). As the regression slopes of the experimental groups did not differ significantly, the type of student teachers could be used as a covariate.

The analysis of the posttest showed a significant main effect for the prompting self-explanations, that was of medium to high practical significance ($F(1,75) = 8.68$; $p < .05$; $\eta^2 = .11$). There was no significant main effect for the instructional explanations ($F(1,75) = 0.37$; $p > 0.1$). The interaction effect reached the level of significance and was of medium practical significance ($F(1,75) = 4.91$; $p < .05$; $\eta^2 = .06$; see Fig. 3).

Table 1: Means and standard deviations of the experimental groups.

	no self-expl. & no instructional expl.	self-expl. & no instructional expl	no self-expl. & instructional expl.	self-expl. & instructional expl
Time-on-task	23.75 (8.82)	46.91 (10.09)	29.64 (9.14)	50.31 (16.76)
Elaborations	--	19.82 (4.51)	--	16.88 (4.51)
Acceptance	4.51 (0.39)	4.39 (0.58)	4.67 (0.65)	4.44 (0.61)
Perceived learning results	3.58 (0.64)	3.98 (0.89)	4.16 (0.77)	3.76 (1.17)
learning outcomes	20.36 (5.46)	25.80 (4.44)	22.75 (5.30)	23.86 (6.29)

As expected, the group without self-explanation prompts and without any instructional explanations performed the worst. Offering instructional explanations fostered learning when self-explanations were not prompted. However, when self-explanations were prompted, supplementary instructional explanations impaired learning. Hence, the most successful group received prompting of self-explanations, but no instructional explanations.
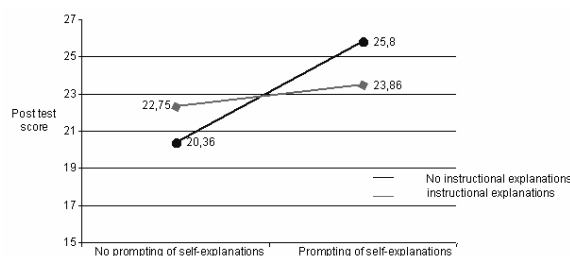

Figure 3: Interaction between prompting self-explanations and instructional explanations with respect to learning outcomes.

As stated in the introduction, the option to request instructional explanations could reduce self-explanation activities. Indeed, the group with self-explanation prompts and additional instructional explanation did elaborate less than the self-explanations only group (about 17 versus 20 elaborations). The difference was significant ($t(32) = 1.72$; $p < .05$; one-sided).

Did the groups differ in their time-on-task? Table 1 displays remarkable differences between groups (24 minutes versus 50 minutes). There was a main effect of prompting self-explanations ($F(1,72) = 64.91$; $p < .05$), with prompting increasing time-on-task. The main effect of instructional explanations reached only a significance level of 10% ($F(1,72) = 2.93$; $p < .10$). There was no interaction effect ($F < 1$). Even though there were differences in time-on-task between the groups, the experimental effects could not be interpreted as mere time-on-task effects. Firstly, typing the self-explanations per se requires time; secondly, as mentioned above, our analyses showed that the quality and not the quantity of learning activities determined the learning outcomes. However, the results indicated that fostering learning by prompting self-explanations requires additional learning time.

An analysis of the treatment effects on perceived learning results (using the type of student teachers as a covariate; there were no significant differences in the regression slopes of the experimental groups) yielded no main effects in the prompting of self-explanations ($F < 1$) and instructional explanations ($F(1,75) = 1.54$; $p > .10$), but a significant interaction ($F(1,75) = 6.36$; $p < .05$). The two groups with self-explanation prompts showed similar perceived learning results of medium size. The group without such prompts and without instructional explanations evaluated their learning results as low. When only instructional explanations were provided, the participants perceived the highest learning results.

The various conditions did not differ in their acceptance by the learners. There is neither a main effect in the prompting of self-explanations ($F(1,76) =$

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1.91; $p > .10$) nor a main effect for instructional explanations ($F < 1$) nor an interaction ($F < 1$).

Discussion

An informal look at the posttest results shows that all student teachers learned substantially about the design of worked-out examples. Hence, we made a significant step towards answering the question as to how to teach teachers knowledge about example-based learning. The extent of learning, however, varied significantly with the experimental conditions. The most effective method was to prompt self-explanations. Instructional explanations were detrimental, at least if they were combined with prompting self-explanations, because they reduced self-explanation activity and thereby the learning outcomes.

Nevertheless, it can be stated that instructional explanations without self-explanation prompts leads to better learning outcomes than leaving the students completely to their own devices. This result is consistent with the findings of Renkl (in press) on the effectiveness of instructional explanations. In Renkl's experiment, no self-explanation prompts were employed.

In contrast to the objective learning outcomes, the highest perceived learning outcomes were found in the instructional explanations-only group. There is an obvious contrast between the real learning outcome and the perceived one. While fostering the learners' own activities objectively leads to the best results, the learners seem to prefer having the explanations presented to them. Apparently, learners do not value instructional measures which require their own activity.

An important consequence of the results presented here is the evident relevance of self-explanation activity for learning outcomes, not only when learning with worked-out examples but also when learning with solved example problems. For this reason the various results concerning the self-explanation-effect are probably transferable to content areas where no worked-out examples can be sensibly constructed. At the same time instructional explanations seem to be less important than self-explanations – equivalent to the results of worked-out example research. However, further research has to be performed using other types of solved example problems.

Looking at the learning processes it is important to note that the mere amount of elaborations substantially predicts learning outcomes. In the near future, the thinking aloud protocols will be analyzed which will give us further insight into the underlying learning processes in the different experimental groups.

Acknowledgments

References

Aleven, V., & Koedinger, K. R. (2000). Limitations of student control: Do students know when they need help? In G. Gauthier, C. Frasson, & K. VanLehn (Eds.), *Proceedings of the 5th International Conference on Intelligent Tutoring Systems* (pp. 292-303). Berlin: Springer.

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. W. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research, 70,* 181-214.

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from examples. *Cognitive Psychology, 20,* 493-523.

Catrambone, R. (1996). Generalizing solution procedures learned from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1020-1031.

Chi, M. T. H. (1996). Constructing self-explanations and scaffolded explanations in tutoring. *Applied Cognitive Psychology, 10,* S33-S49.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13,* 145-182.

Kulhavy, R.W. (1977). Feedback in written instruction. *Review of Educational Research, 47,* 211-232.

Mwangi, W., & Sweller, J. (1998). Learning to solve compare word problems: The effect of example format and generating self-explanations. *Cognition and Instruction, 16,* 173-199.

Quilici, J. L., & Mayer, R. E. (1996). Role of examples in how students learn to categorize statistics word problems. *Journal of Educational Psychology, 88,* 144-161.

Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. *Cognitive Science, 21,* 1-29.

Renkl, A. (in press). Learning from worked-out examples: Instructional explanations supplement self-explanations. *Learning & Instruction.*

Renkl, A., Stark, R., Gruber, H., & Mandl, H. (1998). Learning from worked-out examples: The effects of example variability and elicited self-explanations. *Contemporary Educational Psychology, 23,* 90-108.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10,* 251-296.

Tarmizi, R. A., & Sweller, J. (1988). Guidance during mathematical problem solving. *Journal of Educational Psychology, 80,* 424-436.

Ward, M., & Sweller, J. (1990). Structuring effective worked examples. *Cognition and Instruction, 7,* 1-39.