

Training Principle-Based Self-Explanations: Transfer to New Learning Contents

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Abstract

The present study tested the transfer effects of a short training intervention on principled-based self-explanations. The intervention used fables as well as mathematics examples and problems as "exemplifying" domains for training such self-explanations. The effects were tested in a new learning environment about attribution theory and feedback messages. In this experiment, 58 German high-school students were randomly assigned to the self-explanation training condition or a control condition (i.e., training of mnemonic strategies). The learning outcomes from the learning environment about attribution theory and feedback did not significantly differ between groups. However, those students who also reported to have applied the strategies from the training intervention actually showed the best learning outcomes. Overall, the self-explanation training intervention "convinced" just part of the learners to engage in principle-based self-explanations in a new environment. There seems to be two options to achieve more reliable effects by future training interventions: The learners have to be prompted more clearly that they should employ the learned strategies in the transfer learning environment or the short-term training intervention should be extended to have a stronger effect on spontaneous strategy application.

Keywords: Self-explanation, training intervention, transfer.

Introduction

If students acquire cognitive skills, these skills should ideally be based on an understanding of the underlying domain principles (e.g., Chi & VanLehn, 2010; Goldstone & Day, 2012; Renkl, 2002). Such a conceptual underpinning facilitates the transfer of the acquired skills to new problems for which a modified solution procedure has to be found. In addition, deep conceptual understanding is considered to facilitate further procedural learning (e.g., Rittle-Johnson, Siegler, & Alibali, 2001). In many learning situations, however, the learners acquire cognitive skills without understanding the corresponding domain principles. Thus, a major goal of instruction is to facilitate meaningful learning that strives for a principle-based understanding.

One way to induce a principle orientation for meaningful learning is to prompt learners for principle-based self-explanations (Kalyuga, 2011). For example, Atkinson,

Renkl, and Merrill (2003) encouraged learners to determine the principle (here: probability rule) behind each step of a worked example. This prompting procedure fostered transfer to isomorphic and to novel problems, for which modified solution procedures had to be found. Principle-based prompting also worked in "verbal" domains without mathematical solution procedures. For example, Schworm and Renkl (2007) provided principle-based prompts to learners when they studied video examples of sound scientific argumentation. Such prompts help determine the argumentative structures and, thereby, the argumentation skill. Whereas the Atkinson et al. and the Schworm and Renkl studies analyzed example-based learning, Aleven and Koedinger (2002) showed that principle-based self-explanation prompts also enhance learning by problem-solving (here: in the intelligent tutorial environment Cognitive Tutor). Further, there are numerous studies affirming the positive effects of prompting principle-based self-explanations (e.g., Berthold & Renkl, 2009; Conati & VanLehn, 2000; Renkl, 1997; Schworm & Renkl, 2006).

The successful prompting procedures have, however, significant disadvantages. First, when prompts in the form of external guidance are provided, there is no guarantee that the learners do not fall back on rote learning when the prompts are not present anymore (cf. Wecker & Fischer, 2011). Second, it is a substantial amount of work to enrich learning materials or environments with prompts; it may not be practical to do so for *all* materials a learner may need, or even to know what learning materials a learner may need in the future. It would be far preferable if the learners acquired self-explanation skills that they can use for further self-regulated learning in new learning environments.

There are several tried-and-tested self-explanation training interventions. However, they all have restrictions with respect to fostering principle-based self-explanations when learners study worked examples and solve problems in order to acquire cognitive skills. McNamara and colleagues focus on reading strategies in their self-explanation training interventions SERT and iStart (McNamara, 2004; Levinstein, Boonthum, Pillarisetti, Bell, & McNamara, 2007). These strategies are not tailored to

learning by examples and problem-solving. A restriction of other training interventions for self-explaining examples and problems that have been tested so far is that they employed the same type of materials in the training phase as in a subsequent learning phase (e.g., Bielaczyc, Pirolli, & Brown, 1995). For example, Renkl, Stark, Gruber, and Mandl (1998) trained participants using examples of (compound) interest calculation in order to prepare them for a later learning phase dealing with the same domain. The self-explanation training of Wong, Lawson, and Keeves (2002) focuses on geometry learning in all phases.

The expectation that the self-explanation strategies addressed by these previous training will solely transfer to similar contents seems to be realistic because transfer to dissimilar contexts (e.g., different learning domain) is very hard to achieve (e.g., Detterman 1993; Goldstone & Day, 2012; Perkins, 2009). Nevertheless, some researchers found some training effects that transfer over contents. For example, Chi and VanLehn (2010) had their learners work in an intelligent tutoring environment called "Pyrenees" (domain: probability) that demanded, among other things, a focus on domain principles. The learners were prompted to reason about the principles in order to determine sought values and they had to apply the principles to the problems at hand. It was found that this principle orientation transferred when working in another intelligent tutorial environment (i.e., "Andes"; domain: probability and physics); this was in particular true for learners with less prior knowledge. Note that there was not only a transfer across learning environments (Pyrenees to Andes) but also across learning domains (probability to physics).

Whereas Chi and VanLehn (2010) found transfer of a principle orientation acquired during physics learning, Busch, Renkl, and Schworm (2008) developed a training intervention with the "sole" purpose to foster self-explanations. This short intervention (less than 30 min.) was conducted with the topic "fables." The learners were shown that in order to determine that a short story is a fable one has to self-explain whether some crucial principles were implemented in the story (e.g., animals as actors, hidden message). This intervention showed considerable transfer effects to a rather distant topic: example-based acquisition of scientific argumentation skills. Although this short-term training was surprisingly successful, it had a significant restriction. Although there was transfer from fables to scientific argumentation, it was "just" transfer between verbal domains. As the Busch et al. intervention did not refer to mathematical solution procedures, which are typical not only of mathematics but also of many science sub-domains, we did not expect transfer to the latter domains. Hence, it is sensible to modify the Busch et al. training intervention by including mathematical contents.

The Present Study

We trained high-school students providing self-explanations in two domains. As in the study by Busch et al. (2008) we used fables as "verbal" exemplifying domain, and

mathematics as an algorithmic exemplifying domain. Afterwards the students learned from an example-based learning environment how to apply psychological attribution theory in order to provide feedback that has favorable motivational effects. This content domain was not taught or mentioned in the training intervention. Hence, we test the hypothesis that the self-explanation training using mathematics problems and fables as materials has positive effects on learning about the provision of productive feedback on the basis of attribution theory.

As control group, we did not use a non-treatment group, as these effects might be rather trivial. Instead, we compared the self-explanation intervention with a training intervention on mnemonic strategies. Although the latter strategies might be useful for remembering facts, we hypothesized that the self-explanation intervention is more favorable for high-level learning goals (e.g., applying what has been learnt about feedback to evaluating new feedback messages).

When testing the effects of a modified version of the short training intervention by Busch et al. (2008), we tried to keep the training time short, that is, about half an hour (as in the original training intervention). Such a short training intervention is applicable within the usual class periods in schools. In the self-explanation intervention, we kept the basic example of a fable in order to demonstrate the value of principle-based self-explanations. In addition, we used mathematics examples in order to show how to self-explain while studying mathematics examples and while solving mathematics problems. We saved some training time in order to add mathematics contents by focusing on principle-based self-explanations and leaving out other types of self-explanations (e.g., goal-operation elaborations) that were part of the original training intervention. Nevertheless, we had to shorten the treatment of self-explaining fables in order to keep the intervention time within the limits of about half an hour. A question that arose was whether the training intervention has still transfer effects to other verbal areas, even if the treatment of fables as verbal training examples was substantially reduced. The unique contribution of this study is the evaluation of a self-explanation training intervention that is designed to have across-domain transfer effects, that is, effects that are not bound to the "exemplifying" domains used during training.

Method

Participants and Design

We randomly assigned 58 female high-school students (age: $M = 16.52$, $SD = 0.71$) to two conditions: training intervention on principle-based self-explanations ($n = 31$) and training intervention on mnemonic strategies ($n = 27$). The participants were members of elective courses in psychology from a "mono-educational" (i.e., just female students) *Gymnasium* (i.e., highest high-school track of the German three-track system). The main dependent variable was the learning outcomes in a learning environment that followed the different training interventions. This transfer

environment was about attribution theory and its application to providing productive feedback. The contents that the students learned in this experiment were not directly related to their currently treated topics in their psychology courses. However, they were (validly) informed that the topics fit the overall learning goals of these courses.

Instruments and Materials

Short-term training environments. We compared the transfer effects of two training environments: Training of principle-based self-explanations versus training of mnemonic strategies. They lasted about half an hour. Both training interventions were parallel in a number of features. They both introduced the fictitious character Sarah who had learning difficulties (see Figure 1). In both cases, a friend helps out by suggesting some strategies (i.e., principle-based self-explanations or mnemonic strategies, respectively). Both training modules presented the contents within a dialogue between Sarah und her friend. During the program the learners in both conditions got work sheets in order to practice the respective strategies. Both modules ended with a short summary of the training contents.

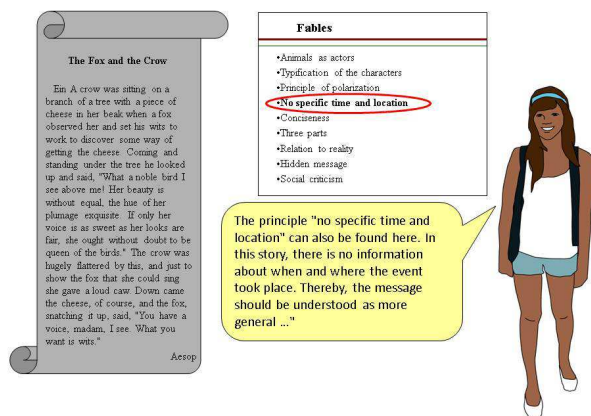


Figure 1: Screenshot from the training intervention module on principle-based self-explanations (translated from German)

The *training intervention on principle-based self-explanation* was divided into two main modules, which explained and practiced principle-based self-explanations when (a) studying an example and (b) solving a problem. The first example in the example-studying section was Aesop's fable "The fox and the crow." We showed that a fable is characterized by several principles or underlying features (e.g., animals as actors, principle of polarization, hidden message) and that the readers have to self-explain a story in terms of above-mentioned underlying features in order to identify the story as a fable (see Figure 1). Next the learners practiced principle-based self-explanations, supported by corresponding prompts, on a work sheet presenting a worked example applying the Pythagorean

Theorem. Hence, a first instance of inter-domain transfer was practiced. In the second part, we supported further transfer by presenting and practicing principle-based self-explanations when solving diverse mathematics problems.

The *training intervention on mnemonic strategies* introduced and practiced three strategies: (a) Using mental images; (b) "Eselsbrücken," which is a German term for (in many cases funny) phrases that interconnect two items (e.g., word in a foreign language and translation). (c) "Mnemonic sentences" similar to "My very educated mother just served us nine pickles" for the planets and their distances to the sun (note, however, that we used other mnemonic sentences because this one does not work in German language).

Transfer environment. The transfer environment first introduced the concept of attribution and explained why attributions are important in learning contexts. Then it introduced the basics of Kelley's (1971) attribution theory, that is, the co-variation model. On this basis, it explained how feedback should be given to students so that functional attributions are fostered. Two small exercises were included in which the participants had to analyze feedback statements. Finally, a summary was provided. The learner worked on average 7.10 min ($SD = 2.02$) in this module (no significant difference between the conditions).

Posttest. The posttest assessing the transfer effects of the self-explanation training consisted of 15 problems (average time: 23 min). In addition, the posttest booklet asked three questions that were to be answered on 5-point rating scales at the very beginning (I found the first program useful; I found the second program useful; in the second program I applied the strategies that I have learned in the first program). After these questions, we presented the problems assessing the learning outcomes.

Three problems asked what should be emphasized in feedback in different circumstances. Six items asked for the attribution theory principles behind exemplary feedback messages (e.g., "In a dance class: *A lot of people struggle with Tango*" (the feedback message itself is printed in italics). Solution: Such feedback suggests attributions to task difficulty and it should "prevent" internal attributions when having difficulties). Four items required writing a short feedback statement for different circumstances. Finally, two items ask for identifying what is problematic with two suboptimal feedback statements. This scale had a good internal consistency (Cronbach's α of .86).

Procedure

The students participated at experimental group sessions in a university computer laboratory (about 20 students per session). The students worked individually in front of a computer. The different computers were randomly assigned to one of the two experimental conditions. These sessions lasted about 100 min. At first glance, this duration is longer than to be expected from the average time of the single phases such as training intervention, transfer environment, and posttest. Note, however, that the faster students had to wait for the slower ones before going on to the next phase.

After some welcome words, we informed the students that they will learn about some learning strategies in a first computer-based learning environment and that they should apply these strategies in a second computer-based learning environment. Subsequently, students were asked to fill in a short paper-pencil questionnaire on demographic data (one page), previous school grade, and on learning goal orientation (Dweck & Leggett, 1988). As the latter scale neither predicted learning outcomes nor interacted with the different treatments we did not consider the students' learning goal orientation in the following.

After completing the questionnaire the students worked on the training intervention modules. Subsequently the students learned about feedback and attribution theory in a second learning program. Finally, they took the posttest.

Results

A significance level of .05 was used for all analyses. We used d as an effect-size measure with values between .20 and .50 classified as small, values between .50 and .80 as medium, and values $> .80$ as large (Cohen, 1988).

We did not find any significant differences between the groups with respect to the grade point average on the last report card or the experience with learning programs (both $F_s < 1$). Eight students said that they have never heard the term attribution. Fifty students said that they have already heard about this term but did not remember its meaning. No student was able to explain what attribution means. Overall, the student had hardly any prior knowledge.

The self-explanation condition scored descriptively higher on the posttest as compared to the mnemonics condition, $M = .55$, $SD = .23$ vs. $M = .48$, $SD = .21$ (M s represent the percentage scores as compared to the theoretically possible maximum). However, this difference did not reach the level of statistical significance, $t(56) = 1.08$, $p = .286$, $d = 0.32$. This relatively weak and statistically not significant effect could be due to the following factors: (a) The effect of the self-explanation training intervention interacts with learning prerequisites (*aptitude-treatment interaction explanation*); (b) some of the learners superficially scanned or quickly read the training module (*scan and skim explanation*); (c) the training module was too difficult at least for some learners (*difficulty explanation*); (d) the learned self-explanation strategies were not applied by some learners in the application environment on attribution and feedback (*production deficiency explanation*).

(a) *Aptitude-treatment interaction explanation*. The most important learning variable with respect to aptitude-treatment interaction is prior knowledge or achievement level (Kalyuga, 2007). The grade point average, as indicator of prior school achievement, was significantly related to the posttest ($r = .37$, $p = .005$). However, there was no interaction between condition and grade point average, with respect to the posttest, $F < 1$. Further exploratory analysis with other learning prerequisites (e.g., grades for mathematics or German; experience with computer-based learning program) did not indicate any aptitude-treatment

interaction. Hence, the aptitude-treatment interaction explanation is likely not true.

(b) *Scan and skim explanation*. If the weak and insignificant transfer effect was due to some learners' just scanning and skimming the training environment, there should be a correlation between learning time and training outcomes. However, the learning time in the training modules was not significantly related to learning outcomes, neither in the whole sample ($r = .05$, $p = .699$) nor in the two sub-groups (self-explanation group: $r = .11$, $p = .551$; mnemonic strategies group: $r = -.15$, $p = .455$). In this context, it should also be noted that the self-explanation group spend more time in the training module, $M = 29.87$, $SD = 6.70$, than the mnemonic group, $M = 24.07$, $SD = 6.89$, $t(56) = 3.25$, $p < .002$, $d = 0.85$. Overall, there is no indication that some learners in the self-explanation condition just quickly scanned the training module, which impeded their learning outcomes. Hence, the scan and skim explanation is likely not true.

(c) *Difficulty explanation*. If the self-explanation training intervention was too difficult for some learners, there should be a substantial number of errors in practice sheets that were included in the learning environment, and the number of errors in these practice sheets should predict lack of transfer. To test this explanation, we coded the quality of the students' responses to the four interspersed work sheets in the self-explanation training module from 1 (completely wrong) to 5 (correct, clear principle application). We found a mean of 4.35 ($SD = 0.55$), clearly indicating that the training was not too difficult for the learners. In addition, there was no significant correlation between the worksheet score and the posttest ($r = .18$, $p = .180$). Overall, the difficulty explanation is likely not true.

(d) *Production deficiency explanation*. We asked the participants to rate on a five-point scale whether they applied the strategies learned in the first module (self-explanation or mnemonics, respectively) in the second module on attribution, as suggested by the experimenter in the beginning of the session. When adding this rating in the prediction of learning outcomes (predictors: condition, rating, and condition by rating), we found a significant interaction effect between condition and reported strategy application with respect to the posttest, $F(1,54) = 9.72$, $p = .003$. To better understand this interaction, we determined the regression scores and their statistical significance in both conditions. In the self-explanation condition, the more the students reported that they applied the learned strategies, the better the posttest performance, $b = 0.09$, $t(29) = 2.59$, $p = .015$. In the mnemonics condition, we did not find a significant relation between self-reported strategy application and posttest performance in the transfer environment, $\beta = -0.07$, $t(25) = -1.89$, $p = .071$. In accord with a production deficiency explanation, these findings indicate that only part of the students applied the learned strategies in the module on attribution and feedback and, thereby, profited with respect to learning outcomes.

In order to get an idea of how many non-applying students were "responsible" for the insignificant overall training effect, we conducted some post-hoc analyses. When we excluded the three students from the self-explanation condition who stated that they did *not at all* apply the strategies (i.e., choosing 1 on the 1 to 5 rating scale of strategy application), there was still no significant effect of condition on learning outcomes. However, when excluded an additional nine students, namely, all students who stated that they did *not* apply the strategies (i.e., choosing 2 on the 1 to 5 rating scale of strategy application), the condition effect gets to be statistically significant (self-explanation condition: $N = 19$; $M = .63$, $SD = .22$; mnemonics condition (as already reported): $N = 27$; $M = .48$, $SD = .21$, $t(44) = 2.23$, $p = .031$, $d = .70$). Hence, only when we consider the (roughly) two thirds of the students that were convinced to apply the strategies, we get a significant effect of the self-explanation training intervention.

The preceding post-hoc analysis might be criticized because we excluded only participants from the self-explanation condition and we, therefore, had rather different group sizes. If we also exclude the ten participants from the mnemonic condition (i.e., roughly the lower third) that reported about low strategy application, we also got a significant group difference: self-explanation condition (as already reported): $N = 19$; $M = .63$, $SD = .22$; mnemonics condition: $N = 17$; $M = .42$, $SD = .23$, $t(34) = 2.70$, $p = .011$, $d = .89$). This finding again underlines that the self-explanation treatment was successful in about two thirds of the cases.

Discussion

We tested whether we could successfully implement a short-term training intervention on principle-based self-explanations that has positive effects on learning in a subsequent learning environment. Unfortunately, we got only a weak and statistically insignificant effect. According to our post-hoc analyses, it is unlikely that this weak effect was due to aptitude-treatment interactions with learning prerequisites, a scan-and-skim behavior of some learners, or the difficulty of the training intervention. Instead, only part of the students (about two thirds) was "convinced" by the training intervention to apply the learned strategies in a subsequent learning environment. Students who applied the strategies profited from the training intervention.

Why did some learners not apply the self-explanation strategies? There are at least three possible explanations: (a) These learners did not find the strategies in the self-explanation training useful; (b) it was not salient enough, at least for some learners, that they were expected to apply the strategies that they have learned in the first environment in the second learning environment; (c) the training intervention was too short to fully change the students' habitual learning behavior.

The perceived usefulness argument can be evaluated by further post-hoc analyses. After completing the learning environment on attribution theory and before they took the

posttest, the learners rated how useful they found the strategy training module. The learners from the self-explanation condition rated this module as rather useful ($M = 4.03$, $SD = 0.98$ (5-point scale from 1, not at all, to 5, fully agree)). The perceived utility predicted to some extent whether the strategies applied ($r = .36$, $p < 0.05$). However, the perceived utility did not interact with the treatment, in contrast to the reported strategy application. Obviously, the (low) perceived usefulness was not a major cause for not applying the strategies and for reduced training effects.

How salient was it for the learners that they should apply the learned strategies in the second learning environment? In the beginning of the experimental sessions, the experimenter informed the students that they should apply the strategies to be learned in a first environment in the second computer-based learning environment. However, this prompt was not repeated (keep in mind that the question of to what extend the strategies learned in the first program were applied was posed after the transfer phase). Note also that in the beginning of the session, the students got a variety of information and were confronted with many new "impressions," that is, they came to a new building (i.e., Department of Psychology), they were introduced to the computer room and the experimenter, they were informed about various aspects of the study, etc. Thus, for some students, the instructions about strategy application might not have been very salient and they might not have been remembered when they began to work on the second learning environment. It seems plausible that - given the short duration of the training intervention so that no profound effect on habitual behavior can be expected - the students would need at least some form of "kick-off" prompt at the start of the transfer learning environment to apply the learned strategies to new contents.

As already argued, the short training duration makes it implausible that the students' habitual strategy use was changed. Against the background of the present intervention's short duration and the corresponding transfer literature (e.g., Detterman 1993; Goldstone & Day, 2012), it can even be regarded as success that about two thirds of the learners transferred the newly learned self-explanation strategies across domains.

In this context, it should also be noted that we have replaced the verbal self-explanation training materials of Busch et al. (2008) to a large degree with mathematical examples. Given that Busch et al. found significant transfer effects across two verbal domains, it can be tentatively assumed that the "verbal part" was too much reduced. Hence, a sensible next step in improving the training intervention would be to extend the verbal part roughly to the length of the Busch et al. intervention. Thus, we extend the verbal part of our training intervention in a next step on our way to develop some type of "generic" self-explanation training. We also intend to test transfer effects on mathematical learning environments.

An alternative explanation for the positive training effect when looking at the two thirds of student reporting strategy

application is that the mnemonic intervention suppressed at least some students' tendency to self-explain spontaneously. Hence, further studies should also include a control condition allowing for spontaneous self-explanations.

Overall, the present study and Busch et al. (2008) have taken partly successful steps towards a self-explanation strategy training that has the potential to achieve across-domain transfer effects. Nevertheless, there is some further research to be done (e.g., extending the intervention; testing transfer to mathematical contents). However, the available findings justify some optimism that we can step by step come to a successful training approach.

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