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Enhancing Example-Based Learning in Hypertext Environments

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Abstract

In previous research, Gerjets, Scheiter, and Tack (2000) demonstrated that learners experience serious difficulties in utilizing instructional examples according to their profitability when interacting with a hypertext-based learning environment. In this paper we focus on possible causes of these difficulties and on different instructional methods for improving learners' utilization of worked-out examples in hypertext environments. The results of two experimental studies are reported.

Learning from Worked-Out Examples: The Role of Example Processing Strategies and Example Design

Research over the last 15 years in the domain of learning and problem solving has demonstrated that instructional examples play an important role for knowledge acquisition in domains like mathematics, physics, or programming (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). In particular for initial skill acquisition, learning from worked-out examples seems to be superior to actively solving training problems (Sweller, van Merriënboer, & Paas, 1998). However, numerous findings also indicate major drawbacks of example-based learning. In particular, poor learners tend to overuse examples during problem solving without reflecting on their appropriateness (VanLehn & Jones, 1993). In addition, learners have difficulties identifying relevant information in worked-out examples and are often distracted by examples' surface features (Ross, 1989). Furthermore, Renkl (1999) assumes that students often suffer from illusions of understanding when learning from worked-out examples. I.e., they may have the false impression of having grasped the solution rationale of an example problem. Finally, learners have difficulties generalizing solutions from examples to novel problems (Catrambone & Holyoak, 1989; Reed, Dempster, & Ettinger, 1985).

A number of empirical studies have identified features of *example processing strategies* and *example design* that are efficient for successful knowledge acquisition (cf. Atkinson, Derry, Renkl, & Wortham, 2000).

Important *strategical aspects* mainly concern the *adequate selection and elaboration* of instructional examples. Reed, Ackinclose, and Voss (1990) showed that learners failed to select sufficiently complex instructional examples for learning although the profitability of these examples for

subsequently solving test problems could be demonstrated. However, Reed, Willis, and Guarino (1994) found that learners who were allowed to select worked-out examples *while solving test problems* were able to select suitable examples. Additionally, it has been shown that *self-explanations* are an important aspect of good learners' example processing (Chi et al., 1989; Pirolli & Recker, 1994; Renkl, 1997). In particular, anticipations of solution steps and inferences with regard to the relations between solution steps, goals, and abstract principles have been proven useful for knowledge acquisition.

With respect to *design issues* it could be shown that *multiple examples* can support schema induction which helps learners to solve novel problems (Cummins, 1992). Providing multiple examples with *different surface features* might further improve this process of abstraction (Quilici & Mayer, 1996). Additionally, it has been proposed that the provision of *completion problems* - where learners have to fill in some details of worked-out examples' solution steps - is a helpful instructional device as it fosters self-explanations (Van Merriënboer, 1990). In particular, presenting completion problems along with evaluative feedback on subjects' gap-filling performance seems to improve learning outcomes. For instance, Stark (1999) showed that learners benefit from such a combination of completion problems and feedback and stresses the point that completion problems foster example elaboration whereas giving feedback on the learning success might prevent learners from *illusions of understanding*.

From these findings on learning from examples it can be argued that *strategies of example selection and processing* as well as *features of example design* have to be taken into account to improve learning outcomes.

The aspect of adopting suitable strategies gains increasing importance the more the control of the learning process is left up to the learner. In learning situations where the learner can *select* instructional material as well as determine the *sequence* and the *pace* of presentation, the importance of strategies increases (Gerjets, Scheiter, & Tack, 2000). Therefore, an identification of suitable strategies of information utilization and an examination of whether learners can adopt these strategies is highly relevant when more focus is put on self-regulated learning in the field of instruction.

Example-Based Hypertext Environments

One domain in which these issues of learner control are stressed is the field of hypertext-based learning where the user can select among different kinds of information and where he can choose according to his goals when the information is to be presented and in which order (Rouet & Levonen, 1996).

On the one hand, this allows for great flexibility and adaptivity of learning and problem solving. Generally, it is assumed that the nonlinear structure of hypertext environments improves learners' ability to use knowledge in a flexible way, so that they learn to apply one information unit to serve different purposes in a variety of situations. Non-linearity also enables learners to utilize information units according to their goals and to their prior knowledge. With regard to example-based learning, providing multiple examples with different surface features in a nonlinear hypertext environment allows the learner to compare examples within one problem category as well as to compare examples between different problem categories. These comparisons are fundamental for processes of abstraction in that they allow learners to identify structural features that define different problem categories. Therefore, non-linearity and the resulting opportunities of flexible information utilization may be especially suitable when learning from examples.

On the other hand, learners can "face new problems in selecting and accessing relevant information" (Rouet, Levonen, Dillon, & Spiro, 1996, p. 3). Problems can arise if learners do not possess the necessary prerequisites to cope with the demands that have been imposed to them by redirecting control over the learning process to them (Rouet & Levonen, 1996). Learning with a nonlinear hypertext increases the amount of control demands by making it necessary that learners permanently make decisions about the profitability of individual information units with regard to their current learning tasks. Even if all information provided is relevant to the current task, the information items may differ with respect to their profitability in terms of their processing costs and their contribution to improving the learning outcome (cf. Pirolli & Card, 1999). Therefore, learners may have to develop adequate strategies of information selection and processing in order to make use of the potential benefits of hypertext-based information presentation.

Based on these considerations a question of central importance in example-based learning with hypertext is whether learners are capable of utilizing examples according to their profitability, i.e., select, sequence, and compare them in a suitable way. Most research on learning from examples up to now has focused on learning situations where learners have been forced to process the examples provided in a predefined sequence and, in some studies, even for a fixed amount of learning time. However, it is not clear whether these findings can be easily transferred to more natural learning situations that allow subjects to select information in different sequences and to control their own pace of studying.

Results of Previous Experiments

In a series of previous experiments Gerjets, Scheiter, and Tack (2000) demonstrated that learners experience difficulties in hypertext environments with regard to their

ability to utilize examples according to their profitability. These experiments were conducted using a web-based hypertext environment for training and testing in the domain of combinatorics (HYPERCOMB). During the learning phase subjects could retrieve abstract information on six problem categories from the domain of combinatorics. Depending on the experimental condition, this abstract information was either not augmented by any additional instructional information or was augmented by one or three worked-out examples that illustrated the six problem categories. Learners could retrieve the information they wanted to study and could determine the pace and sequence of information presentation. When they had the impression that they had learned sufficiently well learners could switch to a test phase where they had to solve three test problems. Automated logfile analyses were used to track subjects' strategic navigation behavior. Additionally, subjects' problem-solving performance was registered.

In order to investigate strategic adaptation to different instructional situation Gerjets et al. (2000) studied learners with either *low or high domain-specific prior knowledge* using different instructional versions of HYPERCOMB (no or one example or three examples per problem category) *with or without time pressure*.

As a result of their experiments Gerjets et al. (2000) showed that learners have difficulties in selecting the most profitable information in a specific instructional situation.

A comparison among the three instructional conditions yielded no beneficial effects of *merely providing* examples compared to providing only abstract information. However, if subjects *made use* of the examples in a suitable way (e.g. by comparing different examples) this clearly improved their learning and problem solving performance compared to subjects who made insufficient use of the instructional material. These findings on information profitability were contrasted with learners' actual information utilization behavior. Despite the fact that example processing proved to be useful, about half of the subjects demonstrated poor example processing strategies as they neither processed each example in the one-example condition more than once nor did they study more than one example per problem category in the three-example condition.

Hypotheses: Possible Explanations for Learners' Problems to utilize instructional examples according to their profitability

There might be two different explanations for learners' problems to utilize instructional examples according to their profitability, which will be described in the following paragraphs. Furthermore, two experimental conditions will be outlined that were designed to counteract these hypothesized causes of subjects' failures in using examples adequately.

Non-linearity

A first explanation is related to the fact that the experimental material is designed as a nonlinear hypertext environment. According to Niederhauser, Reynolds, Salmen, and Skolmoski (2000) additional control demands caused by non-linearity may result in extraneous cognitive load (cf. Sweller, Van Merriënboer, & Paas, 1998), which in turn impedes learning activities. Learners may suffer from

cognitive overload due to additional control and navigational demands caused by the nonlinear environment.

Additionally, learners may be in general overwhelmed by the need to *decide which information is profitable to select in which situation* (cf. Rouet et al., 1996). As a result subjects may be unable to utilize examples according to their profitability, either because of cognitive overload or because of inadequate navigational decisions. In order to counteract these problems of cognitive overload and of information selection we introduced a *linear-hypertext condition* of HYPERCOMB that contained exactly the same information as the *nonlinear-hypertext condition* and that forced learners to recognize every information available in a predefined order. Thereby, only pacing was left up to the learner. Eliminating the need to select and sequence information should reduce extraneous cognitive load and should free cognitive resources for processing instructional examples adequately. Furthermore, profitability judgements are less critical in a linear-hypertext condition.

Illusions of understanding

A second explanation for the insufficient use of the examples provided in HYPERCOMB is not related to the non-linearity of the information presentation but is related to the fact that learners may suffer from *illusions of understanding* when learning from worked-out examples (Renkl, 1999). To prevent learners from such illusions we introduced an instructional condition with incomplete examples and feedback where we presented fragmentized example solutions and asked the learners to complete these gaps by selecting one of two possible multiple-choice answers. After the completion, learners were provided with feedback concerning the correctness of their answers. This procedure may improve intensive example processing as it may help learners to realize that they are far away from an in-depth understanding of the example solutions. As a result, learners may notice that examples proved a profitable source of information and are helpful in order to overcome these comprehension failures.

In experiment 1 a nonlinear version of HYPERCOMB with three complete worked-out examples per problem category (baseline condition) was compared to a linear version in order to test the first hypothesis that subjects' inadequate use of examples results from additional navigational and control demands in nonlinear hypertext.

In experiment 2 the baseline condition was compared to a condition with three incomplete examples with feedback in order to test the second hypothesis that subjects' failures in using examples adequately results from an illusion of understanding.

We expected that both instructional manipulations should increase the time spent on processing examples and thereby improve learning outcomes. Additionally, we assumed that the instructional devices would especially foster learning outcomes of subjects with low prior knowledge who may suffer from control demands as well as from illusions of understanding to a greater extent than learners with high prior knowledge.

Experiment 1: Linear Hypertext

Method

Participants Subjects were 80 students of the Saarland University, Germany, who either participated for course credit or for payment. Average age was 23.4.

Materials and procedure Subjects used the HYPERCOMB environment for learning and problem solving. First, a short introduction to the domain of combinatorics was presented. During the subsequent learning phase subjects could retrieve abstract information on six problem categories (defined by their associated formula) from the domain of combinatorics. Additionally, three worked-out examples that varied with regard to their complexity and their cover story were provided for each problem category. In the test phase subjects were instructed to solve three probability word problems. Neither the abstract information nor the worked-out examples of the learning phase were available during the test phase.

Design and dependent measures As a first independent variable two levels of domain-specific prior knowledge were introduced. Additionally, two different instructional conditions were implemented (2 x 2 design):

In the *nonlinear-hypertext condition (baseline)* learners could choose by themselves which information to retrieve (i.e., abstract information and three different examples per problem category) and in which sequence to pursue. Learners could retrieve all information pages as often as they wanted and they could study them as long as they wanted. The learners themselves controlled the learning process so they could as well neglect all the provided information as study them very carefully. This condition served as baseline condition.

In the *linear-hypertext condition* the same instructional material as in the first condition was presented in a linear fashion. Learners had to follow a so-called *guided tour* through the hypertext environment by using "next"-buttons to get from one page to another. All problem categories were explained successively. For each problem category, first the abstract information page was displayed followed by three example pages. Every information page was presented only once, learners could not look back to information already seen and they could not skip any of the information. Therefore, selection and sequencing of the information pages were controlled by the system and only pacing was left up to the learner.

In the test phase subjects had to solve three word problems by marking the appropriate solution principle and the values of two variables for each of the test problems in a multiple-choice form. No calculations had to be made. One error was assigned for each wrong answer (i.e., subjects could obtain overall error rates between 0 and 9). Problem-solving time as well as learning time on example pages and on abstract pages was recorded by using logfiles. Following the test phase subjects had to pass a knowledge test with multiple-choice questions related to abstract concepts from the domain of combinatorics. Similar questions were posed as a pretest at the beginning of the experiment to register subjects' domain-specific prior knowledge. Subjects were

assigned to high and low prior knowledge groups by means of a median splits according to their pretest results.

Results and Discussion

First, we compared high and low prior-knowledge subjects learning either in the nonlinear or in the linear-hypertext condition within the two levels of prior knowledge with regard to their pretest errors (table 1). An overall ANOVA (instructional condition x prior knowledge) yielded no differences between the instructional conditions ($F < 1$).

Table 1: Time data (in sec) and error rates (in %) as a function of prior knowledge and instructional condition

Instructional condition	Nonlinear		Linear	
	High	Low	High	Low
Pretest errors	28.6	63.2	30.3	64.3
Time on example pages	608	465	948	1069
Problem-solving time	602	550	617	606
Problem-solving errors	33.3	42.2	27.2	39.4
Knowledge-test errors	11.0	32.0	18.5	26.5

Time data With regard to example-processing time, an overall ANOVA (instructional condition x prior knowledge) yielded a significant main effect of instructional condition. Subjects in the linear-hypertext condition spent more time on example pages than subjects in the nonlinear-hypertext condition ($F(1,76) = 36.39$; $MS_E = 122363.7$; $p < .001$). Additionally, it could be shown that there was no difference between subjects with high and low prior knowledge concerning example processing time ($F < 1$). The interaction between instructional condition and prior knowledge was marginally significant ($F(1,76) = 2.84$; $MS_E = 122363.7$; $p < .10$). The increase of example-processing time due to the linear information presentation was slightly more pronounced for subjects with low prior knowledge ($t(38) = 5.37$; $p < .001$) than for subjects with high prior knowledge ($t(38) = 3.13$; $p < .01$).

Furthermore, we analyzed whether there was a *trade-off* between example-processing time and problem-solving time, in that learners in the nonlinear hypertext-condition might need less time for studying the examples but more time for later problem solving. However, an ANOVA for problem-solving time yielded no significant results (all $F_s < 1$).

Performance data In order to test the assumption that an increase in example-processing time leads to better problem-solving performance, we conducted an overall ANOVA (instructional condition x prior knowledge) that, however, only yielded a significant main effect for prior knowledge ($F(1,76) = 5.59$; $MS_E = 399$; $p < .05$). There neither was a main effect for instructional condition nor was there an interaction between instructional condition and prior knowledge (both $F_s < 1$).

Besides problem-solving performance we also analyzed knowledge-test performance as an indicator of learning success. An overall ANOVA (instructional condition x prior knowledge) for knowledge-test errors yielded a main effect for prior knowledge ($F(1,76) = 10.51$; $MS_E = 400.1$; $p < .01$) which was due to the high degree of item overlap between the pretest and the knowledge test at the end of the

experiment. There was, however, no main effect for instructional condition as well as no interaction (both $F_s < 1$).

To conclude, providing subjects with linear hypertext increased example-processing time to a large extent as expected. However, this increase in time spent on examples was not accompanied by the expected gains in performance. Furthermore, it could be shown that learning in the nonlinear-hypertext condition was even more efficient because subjects needed less example-processing time for achieving the same level of performance without increases in problem-solving time. Therefore, our first explanation that subjects shallow example processing in hypertext environments observed in previous experiments (Gerjets et al., 2000) can not be traced back to additional control and navigational demands caused by nonlinear information presentation: Reducing these demands does not result in improved performance although example utilization behavior is intensified.

Thus, it seems that merely quantitative increases in example-processing time are not sufficient to ensure successful learning. Therefore, in experiment 2 we implemented incomplete examples with feedback as an instructional method that focuses on more qualitative improvements of example processing instead of only increasing example-processing time. This is in accordance with our second hypothesis that superficial example processing can be traced back to illusions of understanding when learning from worked-out examples.

Experiment 2: Incomplete Examples with Feedback

Method

Participants Subjects were 80 students of the Saarland University, Germany who either participated for course credit or payment. Average age was 23.7 years.

Materials and procedure Subjects used the same HYPERCOMB environment for learning and problem solving as the subjects in the nonlinear-hypertext condition in experiment 1. It consisted in a short introduction to combinatorics, a learning phase with abstract information and three worked-out examples per problem category, and finally a subsequent test phase with three probability word problems.

Design and dependent measures As a first independent variable two levels of domain-specific prior knowledge were introduced. Additionally, two instructional conditions were implemented (2 x 2 design):

As a *baseline condition* we used the nonlinear-hypertext condition from experiment 1 where subjects could decide by themselves which information to review (abstract information and three fully worked-out examples per problem category) and in which sequence to pursue.

In the *feedback condition* the solution steps of the worked-out examples were fragmented and subjects were asked to fill these gaps by choosing among two multiple-choice answers. It is, however, important to note that subjects could decide by themselves whether they filled in the gaps and used the opportunity to receive feedback or not. Every

example solution was fragmented two or three times and the gaps were related to structural features of the problem categories. After having determined the gap-filling answer subjects automatically received feedback on whether their answer was right or not. In case of choosing the wrong alternative the right answer was presented.

The subsequent test phase was identical to experiment 1. As dependent measures error rates and time data were recorded. In the feedback condition the frequency of feedback utilization was additionally registered. As in experiment 1 subjects had to pass a knowledge test with multiple-choice questions related to abstract concepts from the domain of combinatorics after the test phase. Subjects' answers to similar questions at the beginning of the experiment were used to distinguish between low and high prior-knowledge subjects.

Results and Discussion

The results of experiment 2 are shown in table 2. A first comparison revealed that there were no differences between the instructional conditions with respect to pretest errors ($F < 1$). (cf. table2).

Table 2: Time data (in sec) and error rates (in %) as a function of prior knowledge and instructional condition

Instructional condition	Baseline		Feedback	
	High	Low	High	Low
Pretest errors	28.6	63.2	33.6	63.7
Time on example pages	608	465	692	785
Problem-solving errors	33.3	42.2	36.4	46.1
Knowledge test errors	11.0	32.0	21.5	27.0

Time data In order to test the hypothesis that subjects in the feedback condition process the examples more intensively than subjects in the baseline condition, we conducted an overall ANOVA (instructional condition x prior knowledge) for the time spent on example pages. However, this ANOVA only yielded a marginally significant main effect for instructional condition ($F(1,76) = 3.67$; $MS_E = 222102.5$; $p < .10$) with subjects in the feedback condition spending more time on studying example pages than subjects in the baseline condition. There was neither a main effect for prior knowledge ($F < 1$) nor an interaction ($F(1,76) = 1.25$; $MS_E = 222102.5$; $p > .40$).

Performance data With regard to problem-solving errors an overall ANOVA (instructional condition x prior knowledge) yielded no main effect for the instructional condition ($F < 1$). Thus, although there was a slight increase in example-processing time in the feedback condition this increase was not accompanied by respective improvements in problem-solving performance. For prior knowledge, the analysis yielded a main effect ($F(1,76) = 4.08$; $MS_E = 658.8$; $p < .05$). No interaction between the two factors could be demonstrated ($F < 1$).

Additionally, we conducted an ANOVA (instructional condition x prior knowledge) for knowledge-test errors, which yielded no significant main effect for the knowledge test errors ($F < 1$). The interaction between these two factors was marginally significant ($F(1,76) = 3.56$; $MS_E = 381.3$; $p < .10$).

To conclude, at first sight asking subjects to fill in gaps and providing feedback on these gap-filling activities does not seem to be an effective way of improving subjects' learning outcomes in example-based hypertext environments. However - because the use of feedback was not obligatory - it can be expected that only subjects who retrieved feedback sufficiently would often show better learning outcomes.

Therefore we calculated the correlation between the number of times subjects used feedback and the resulting learning outcomes in the feedback condition for high and low prior-knowledge subjects separately. These analyses show that subjects with low prior knowledge indeed benefited from an extended use of feedback (correlation between frequency of feedback utilization and problem-solving errors: $r = -.45$; $p < .05$; knowledge-test errors: $r = -.44$; $p < .05$, one-tailed test) whereas there were no or only weak associations between frequency of feedback utilization and learning outcomes for high prior-knowledge subjects (problem-solving errors: $r = -.12$; $p > .30$; knowledge-test errors: $r = -.31$; $p < .10$).

To sum up, subjects with low prior knowledge who made sufficient use of feedback clearly improved their problem-solving performance compared to subjects with low prior knowledge who made insufficient use of the instructional material. This is in line with our second hypothesis that the provision of incomplete examples with feedback may be useful to reduce illusions of understanding. These findings on the profitability of feedback information for learners with low prior knowledge were contrasted with their actual information utilization behavior in a next step of analysis: Despite the fact that the use of feedback proved useful for learners with low prior knowledge, they did not retrieve feedback more often than learners with high prior knowledge ($t(38) = -.42$; $p > .60$; 2-tailed test). To conclude, although the use of feedback fostered problem-solving and knowledge-test performance of low prior-knowledge subjects they did not use it more extensively. Thus, similar to the findings of example utilization it could be demonstrated again that subjects may experience serious difficulties in utilizing beneficial information provided in hypertext-environments according to its profitability.

Conclusions

With regard to the impact of two different instructional manipulations reported in this paper the following conclusion can be drawn. Although a linear information presentation increases example-processing time this does not automatically lead to improvements in learning outcomes. Linear presentation might reduce extraneous cognitive load due to control and navigational demands in nonlinear hypertext environments, however, this may also imply that learning advantages of nonlinear environments are neutralized. I.e., learners in a linear environment no longer have the opportunity to select and sequence information according to their needs. This lack of opportunity to self-control information utilization also may impair important processes of example comparison. Therefore, there may be a trade-off between the benefits and the drawbacks of non-linearity.

With regard to the provision of incomplete examples with feedback it could be demonstrated that this

instructional device was beneficial for subjects with low prior knowledge but that these subjects often made insufficient use of it.

Therefore, learners do not only have problems in utilizing worked-out examples according to their profitability for learning but also in using feedback extensively when learning in nonlinear environments. On the one hand, learners skip helpful information like feedback if they can control their learning process by themselves. On the other hand, when restricting learner control by presenting information in a linear environment learning becomes less efficient.

Therefore, the development of a learning environment where both of these findings are combined might be most successful. It can be assumed that learning in a nonlinear hypertext environment might be improved by forcing subjects to recognize information units of crucial importance for learning - like a minimal number of examples or the use of feedback on example completions. When developing learning environments, the specific learning situation must be considered to guarantee the advantages of non-linearity and at the same time to reduce the drawbacks by forcing the user to recognize profitable information. There must be a balance between the control that is given to the learner and the system control.

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