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EFFECTS OF A METACOGNITIVE PROMPTING PROCEDURE IN THE CONTEXT OF A COMPUTER-BASED LEARNING ENVIRONMENT: PRACTICAL RELEVANCE AND EXPLANATION BY METACOGNITIVE AND MOTIVATIONAL PROCESSES

Abstract. In the context of a study on learning statistics with a computer-based learning environment, knowledge acquisition was fostered significantly by an economic metacognitive prompting procedure. Students of education prompted by this procedure (n=29) outperformed students (n=28) coping with the learning environment without being prompted; this effect proved to be stable. Concerning time on task and various learning prerequisites, both groups did not differ significantly. In this paper, we focus on two questions: Are these effects practically relevant? And are they mediated rather by metacognitive or by motivational processes? Analyses of the students’ post-test solutions, of their selections during the learning phase and the reasons given for these selections were carried out; in addition, interaction and motivational effects were analysed. Analyses based on domain-specific theoretical criteria showed that the prompting procedure increased the quality of the learners’ knowledge structure. Quantitative and qualitative evidence rather support the metacognition hypothesis than the motivation hypothesis.

1. THEORETICAL BACKGROUND

In several disciplines of the social sciences, empirical research methods and statistics form an important part of the curriculum. For many students, however, this subject poses serious difficulties (Broers & Imbos, in press; Stark & Mandl, 2000). Many domain experts have complained repeatedly about the flawed application of core statistical concepts and procedures (e.g., Cohen, 1990, 1994; Gigerenzer, 2000; Haller & Krauss, 2002).

Starting from misconceptions, comprehension problems and metacognitive deficits of the students which were diagnosed in the important sub-domain of correlation, a computer-based learning environment was developed (Koralle). This learning environment is based on a systematic combination of worked-out examples and problem-solving tasks (Krause, Stark, & Mandl, in press). This combined learning method already proved to be effective in another domain (interest calculation) which has some relevant characteristics in common with correlation: both interest calculation and correlation are rather basic and important for novices of the respective fields, they are highly structured and solutions of typical problems can be easily presented in a schematized manner (Stark, 2001).

In an experimental study (Stark, Krause, Tyroller, & Mandl, 2003), this learning environment proved to be effective. Students learning with Koralle in addition to
attending a regular lecture on correlation outperformed students of the control group who only attended the lecture: they attained significantly and substantially higher scores in a knowledge test which focused on different types of knowledge about correlation (experimental group 1 with additional prompting: \(d = 2.49\); experimental group 2 without additional prompting: \(d = 1.39\). The two experimental groups did not differ from the control group with respect to cognitive, metacognitive and motivational learning prerequisites.

Students in experimental group 1 who were prompted to give reasons for their selections in the course of learning with examples and problem-solving tasks performed significantly and substantially better in the knowledge test than their colleagues in experimental group 2 who worked with Koralle without the prompting procedure (\(d = .71\)). The effects of this procedure which was supposed to foster learning outcomes by evoking metacognitive processes were stable, too (after four weeks: \(d = .94\)). The internal validity of this comparison was secured by controlling time on task as well as cognitive, metacognitive and motivational learning prerequisites.

However, facing these results, two aspects need closer investigation. First, as the judgement of effect size measures is based on conventions and not on domain- and task-specific considerations about the quality of achieved effects, the critical question has to be posed whether these effects are really practically relevant in the sense that the quality of the knowledge structure is improved.

Secondly, it is not clear how these effects can be interpreted. The prompting procedure was conceptualized to stimulate metacognitive processes (by increasing mindfulness, Salomon & Globerson, 1987) in general and especially metacognitive control. However, the prompting procedure might also enhance learning through motivational processes, for example by increasing the students’ motivation to invest time and effort, i.e. their persistence.

The main goal of the paper to be presented is to answer these two questions.

2. SUBJECTS AND INSTRUMENTS

Participants were 57 students, most of whom studied education. 27 students were randomly assigned to the first experimental condition (with prompting procedure), 28 students to the second (without prompting procedure). 67 students who attended a regular lecture on empirical research methods but did not participate in the experiment were used as a control group.

All tests and rating scales employed in the study were sufficiently reliable (Cronbach’s Alpha > .65); most of them were developed and tested in the context of former studies on example-based learning in other domains (see Stark, 2001).
3. ANALYSES

3.1. Question 1: Does the prompting procedure improve the quality of knowledge structure?

In order to answer the first question, theoretical criteria to evaluate the quality of the students’ knowledge structure (as indicated by their post-test solutions) were developed by two domain experts. For each task of the post-test, the type of knowledge which is necessary to solve it was specified. It was differentiated between propositional knowledge, action knowledge, combination of situational and action knowledge, and conceptual understanding which is indicated by a competent application of all three knowledge types. Moreover, for each task a special criterion was defined (for example the correct application of a special proposition) which indicates that the main learning goal concerning the task is achieved. One domain expert evaluated the post-test solutions of the students with regard to the specified criteria. Evaluation problems were solved in cooperation with the other expert.

3.2. Question 2: Does the prompting procedure enhance learning through metacognitive or through motivational processes?

As the second question is more complex, various quantitative and qualitative data had to be analysed. At first, it was investigated to what extent the effect of the prompting procedure was moderated by the learners’ metacognitive prerequisites which were recorded before the learning session started; such an effect could indicate the compensatory function of this procedure.

Secondly, it was investigated to what extent students in the two experimental groups differ with respect to time on task (assessed on the basis of the logfile data). On the one hand, time-on-task data are rather vague indicators of the learning behaviour and generally difficult to interpret because several factors can cause differences in time on task, such as prior knowledge or motivation. On the other hand, many of these factors can be regarded as controlled: learners in both experimental groups did not differ with respect to cognitive, metacognitive and motivational prerequisites. Since pilot tests showed that typing in reasons for selection in the learning phase is not very time-consuming, only small differences ranging from 5 to maximally 10 minutes were expected. So, differences clearly above 10 minutes might be interpreted in terms of differences in motivational processes (induced by the prompting procedure) which made learners invest more learning time.

In addition to this rather speculative indicator of motivational differences, aspects of the learning behaviour were analysed which allow a more distinct motivational interpretation. Apart from the tasks that were presented automatically, the learners could select additional tasks to work on. Moreover, they could chose whether they wanted to study a worked-out example or work on a problem-solving task. Differences in the number of voluntarily selected tasks can be interpreted as motivational differences. Differences in the number of voluntarily selected tasks
which are worked on by *self-regulated problem solving* and not by studying a worked-out example are even stronger indicators of (motivationally induced) engagement.

As students in the prompting condition had to give reasons for their selections in the learning process by typing them into “prompting windows”, the logfiles also provided some *qualitative* indicators of the learning process. Against the background of theoretical considerations, reason categories were developed and modified iteratively on the basis of logfile data of pilot subjects. The following categories were used for coding the students’ reasons: positive/negative monitoring, self-regulation, implicit learning theories/epistemological beliefs, motivation/emotion positive, motivation/emotion negative and other aspects. According to Hasselhorn (2001), the first two categories represent *executive* aspects of metacognition (the control component of the traditional metacognitive perspective; see, e.g., Flavell, 1976). The third category is a combination of *systemic* and *epistemic* knowledge aspects (the traditional knowledge component of metacognition). The last two categories focus motivational and emotional aspects. Besides, it was counted how often students ignored the “prompting window”, either by not filling in anything or by typing in nonsense. Two domain experts coded the logfile data. Coding problems were solved discursively. The inter-rater reliability was sufficient (kappa > .75).

Additionally, motivational effects of the prompting procedure were investigated by comparing students of both experimental groups with respect to subjective learning outcomes and acceptance of the learning environment.

4. RESULTS AND INTERPRETATION

4.1. Question 1: Does the prompting procedure improve the quality of knowledge structure?

The criteria-based qualitative analyses of the students’ post-test solutions showed that the prompting procedure fostered the *quality* of the students’ knowledge structure. Especially in the more sophisticated knowledge types, students in the prompting condition achieved significantly higher percentages of the pre-defined learning goal criterion (combination of situational and action knowledge: 85.7 % vs. 48.3 %; conceptual understanding: 67.9 % vs. 41.4 %). Both differences are practically relevant. Concerning propositional knowledge, the difference in proportional goal achievement was only marginal (39.3 % vs. 37.9 %).

The effects of the prompting procedure on total post-test performance were moderated by the students’ metacognitive prerequisites. In the prompting condition, there was only a weak and not statistically significant relation between metacognitive prerequisites and learning outcomes ($r = .19, \text{n.s.}$); in the condition without prompting procedure, however, this relation was strong ($r = .64$) and statistically significant. The difference between both correlations was significant, too. These findings show that the prompting procedure reduced the importance of metacognitive prerequisites for successful learning. For learners with unfavourable metacognitive prerequisites, this procedure had a *compensatory* function. Learners
with more advantageous metacognitive prerequisites were neither aided nor hampered by the prompting procedure; obviously, they did not need this kind of additional support.

4.2. Question 2: Does the prompting procedure enhance learning through metacognitive or through motivational processes?

Interestingly, both experimental groups only marginally differed in the time they invested to work with Koralle. This indicator of the learning behaviour might be rather vague and difficult to interpret. However, at least indirectly it provides some evidence against the hypothesis that the prompting procedure primarily had a motivating function: it did not evoke motivational states that resulted in investing more time on task. Both experimental groups also did not differ significantly concerning the number of selected additional tasks and the number of selected tasks worked on by problem-solving (and not by studying worked-out examples). Especially the second finding does not support a motivational interpretation of the effects the prompting procedure had on learning outcomes.

More direct evidence against the motivation hypothesis stems from the analysis of motivational effects: both experimental groups neither differed with respect to subjective learning outcomes nor concerning acceptance of the learning environment. Thus, there was no additional motivating effect of the prompting procedure. In both conditions, the students evaluated their learning progress and the learning environment remarkably positive. On the two rating scales with a theoretical maximum of 6.0, the group means only varied between 4.5 and 4.9 (the standard deviations varied between .5 and .8).

However, the argumentation provided so far is seriously flawed in so far as evidence against the motivation hypothesis does not automatically support the metacognition hypothesis. In order to test this hypothesis more directly, extensive qualitative analyses of the reasons which the prompted learners provided were carried out. From 383 coded reasons, 143 (37.0 %) fell in the monitoring category, 86 (22.5 %) in the self-regulation category, 73 (19.1 %) in the implicit learning theory/epistemological beliefs category, 52 (13.6 %) in the motivation/emotion positive category, and 22 (5.7 %) in the motivation/emotion negative category. The residual category was coded only 7 times (1.8 %). Only 6 times learners did not give any reasons at all. First of all, these frequency data clearly demonstrate that the prompting procedure was accepted by the learners (manipulation check). Secondly, and this is more important in the context of the provided argumentation, the data show that the majority of reasons given by the learners are directly related to metacognitive control processes and metacognitive knowledge aspects. Thirdly, at least some of the reasons coded as motivational/emotional might result from the learners’ reflections about their own preparedness to invest further effort in coping with comprehension problems etc. That is, even reasons in the motivational/emotional category can be more or less closely related to underlying metacognitive processes.
Altogether, both direct and indirect evidence rather support the metacognition hypothesis and do not (or at least not directly) support the motivation hypothesis. That is, as intended, the prompting procedure seems to stimulate metacognitive processes and does not or at least not primarily work via motivational processes.

5. OUTLOOK

The first question clearly can be answered with “yes”: the effects of the implemented prompting procedure on knowledge acquisition are practically relevant, the quality of the learners’ knowledge structure was distinctly fostered by the procedure.

The answer to the second question is not so clear. In part, this is the consequence of the complexity which inheres in the question: it is generally difficult to clearly separate metacognitive from motivational processes. Multiple quantitative and qualitative evidences referring to moderating prerequisites, learning processes and motivational consequences had to be integrated. Altogether, the analyses rather support the metacognition hypothesis than the motivation hypothesis. However, it has to be admitted that at least some of the provided analyses are speculative and that the whole argumentation procedure mainly follows an exploratory rationale. Therefore, the presented results are not powerful enough to falsify the motivation hypothesis.

From a pedagogical perspective, this is not problematic at all: the implemented procedure was not only highly economic and effective. It also had no negative effects on motivational aspects. So the question whether these positive effects are induced by metacognitive or by motivational processes might be neglected.

However, from a theoretical perspective, this question is important. In order to find a clear cut answer, more powerful analyses are necessary. In the context at hand, it was not possible to analyse qualitative logfile data of the non-prompted learners because these data were created by the “prompting window” which was only presented to the prompted group. Both from the perspective of internal and external validity, it would not have been intelligent to work with a third experimental group which is provided with a similar window but no specific instruction. Working with such kinds of control groups would at best result in more open questions. Perhaps additional insights about the functioning of the prompting procedure could be gained by interviewing the prompted learners on selected aspects of their learning behaviour and/or by working with retrospective thinking aloud methods. As the learning sessions were video taped, the learners could be confronted with selected video sequences. Although these analyses are certainly not more powerful than the ones which were carried out so far, they might still enrich the presented findings by adding new perspectives.
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REFERENCES


