Abstract. Cognitive and metacognitive prompts are a central support procedure in eHELP, a computer-based environment that supports the writing of learning protocols. The prompts are adapted based on the results of a deficiency analysis that uses either an integrated learning strategy questionnaire or a meta-knowledge test. To investigate the effectiveness of the adaptation of the prompts, an experiment was conducted \((N = 79)\). The students revised a learning protocol and were supported either by adaptive prompts, based on the results of one of the two diagnostic instruments, by randomly selected prompts, or they revised their protocols without any prompts. Adaptive prompts improved the quality of the learning protocols and fostered the acquisition of declarative knowledge and comprehension irrespective of the applied diagnostic instrument. Hence, adaptive support for open-ended design tasks (e.g., writing learning protocols) can be improved by making use of strategy assessment by built-in questionnaires.

1. INTRODUCTION

Learning in higher education encompasses many demanding tasks. One task required of students is to process huge amounts of information – and that usually within a short period of time. Information processing in this context should be more than passive reception with subsequent reproduction. It should include self-guided analysis, critical reflection, as well as assimilation and integration of new knowledge with prior knowledge.

A promising approach to foster such productive learning activities is the use of learning protocols. A learning protocol typically represents a written explication of one’s own learning processes and outcomes. When this occurs over an extended period of time, it is called a learning diary (Nückles, Schwonke, Berthold, & Renkl, 2004). The learning diary method aims at stimulating deeper processing and sustained retention of the learning material. This should be accomplished by organizational, elaborative, and metacognitive activities performed by the students. However, the results of Nückles et al. (2004) indicate that elaboration is often neglected in favor of mere exposure, that is, learning contents are only summarized, and reflections on one’s own learning behavior are rare.

In order to help students write more productive learning protocols we have developed and implemented a blended-learning approach (i.e., a combination of lectures and virtual learning). In traditional university seminars within our Educational Psychology program we had students write learning protocols. The writing of the protocols was “tutored” by the computer-based learning environment eHELP (acronym for electronic support of writing and administering learning protocols [in German]). With this cognitive tool (i.e., an artifact that can be used in everyday life to meet real study requirements) learning protocols can be planned, generated, evaluated, revised, and exchanged with others. The iterative phases of
planning, production, and revision (Hayes & Flower, 1980) are supported by a number of different measures (for details about eHELp, see Nückles et al., 2004). One central support procedure is the provision of organizational, elaborative, and metacognitive prompts to foster cognitive and metacognitive learning activities.

Prompts are an effective way to stimulate learning activities (Pressley et al., 1992). Their usefulness is reported in a number of studies (e.g., Berthold, Nückles, & Renkl, 2003; Conati & Van Lehn, 2000). Berthold et al. (2003), for example, had undergraduate students of psychology ($N = 84$) receive one of four instructions for writing a learning protocol about a videotaped lecture on developmental psychology they had attended. The instruction included either six cognitive prompts (e.g., "How would you summarize the main points in your own words?") or six metacognitive prompts (e.g., "Which main points haven’t I understood yet?"), a mixture of three cognitive and three metacognitive prompts, or no prompts at all (control condition). The results of that study showed that learners who received cognitive, or cognitive and metacognitive prompts significantly outperformed the control group (no prompts) with regard to the amount of cognitive and metacognitive activities in the learning protocols, the learning outcomes on both an immediate comprehension test and a 7-day-delayed retention test, and the accuracy of self-assessment in these tests. These findings point to the possibility of prompting productive learning activities in learning protocols but interestingly, the effective prompts were not perceived as more helpful by the learners.

Yet, for a continued application of a learning activity learners must perceive the prompts as helpful (King, 1994). It is well-known that students are often unwilling to replace well-established learning habits with new ones or to integrate new habits into their existing repertoire (Mandl & Friedrich, 1992). Dysfunctional subjective expectations and beliefs regarding their relative effectiveness and economy can account for this (Doyle & Ponder, 1977). Hence, to adequately consider this relation of costs and benefits we employed adaptive support to simultaneously reduce the costs and raise the benefits of the application of the learning diary method, and by doing that, secure the motivation of the students to adopt it as a powerful learning strategy.

In addition, the research on aptitude-treatment interactions (e.g., Cronbach & Snow, 1977) has shown that learning outcomes are related to variations of the educational treatment (i.e., the conditions or environments that support learning) and individual differences in aptitudes (i.e., knowledge, skills, and personality traits). Therefore, Shute and Towle (2003) recommend capitalizing on learner characteristics such as knowledge, cognitive abilities, or learning styles to improve instruction. The instructional dialogue between a human teacher and a student is characterized by ‘real-time adaptation’ of the teacher’s supporting activities to the actual knowledge and to the student’s aptitudes (Schulmeister, 1996). Because cognitive tools are not explicitly designed to support learning directly, but to promote it indirectly by supporting certain activities, adaptive instructional guidance is regarded as particularly important, but it is seldom realized (Mandl, Gruber, & Renkl, 1997).

One way to reduce some of the cognitive and motivational impediments is to adapt the learning environment as well as possible to the needs of the students. A
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A system (e.g., a computer-based environment) can be called adaptive if it is able to adjust itself to changing conditions (Leutner, 1995). There are many system features that are possible candidates for adaptation (e.g., sequencing of content, organization of dialogs, or prompts) relying on a number of variables (e.g., domain knowledge, errors, tasks, or learning strategies). Furthermore, adaptation can serve a number of different purposes (e.g., compensation, stress reduction, or support) employing a variety of diagnostic strategies (e.g., user monitoring, modeling of the task, or diagnosis of knowledge and learning styles); for an overview see Specht (1998). In eHELp adaptation is realized by providing only those scaffolds and hints that are needed and only when they are needed. Such adaptive provision of support also helps to keep the workload within acceptable limits (Sweller, Van Merrienboer, & Paas, 1998).

A prerequisite of adaptive behavior is a sufficiently accurate analysis of variables relevant to the learning process. However, compared to a (sensitive) human tutor, computer-based learning environments, first of all intelligent tutoring systems (ITS), are still far from optimal at analyzing and using present and previous declarative, procedural, or conditional knowledge, particularly at tasks with much room for maneuver (Friedrich & Mandl, 1997; Mandl et al., 1997). However, minimum room for maneuver is essential for self-guided learning. Adaptive support is even more difficult in ill-structured domains like writing. Writing can be classified as an open-ended design problem, that is, in the writing process there is no single fixed goal (Haake & Neuwirth, 1993). Furthermore, writing is “under-constrained”, there is more than one way to write a text and more than one text can meet an author’s writing goals. In summary, adaptation in cognitive tools that are intended to support open-ended design tasks is rarely realized because of the conceptual and technical difficulties of building “intelligence” into the systems. Therefore, it is worth thinking about ways to involve the human users in the difficult task of generating a sufficiently reliable user model as recent approaches already do (Kay, 1995).

In eHELp the prompts are generated on the basis of the results of a deficiency analysis applied during the first use of the program. Users have to fill in a questionnaire concerning their habitual use of learning strategies and learning techniques. The questionnaire comprises twenty-five items covering organizational, elaborative, and metacognitive strategies (Weinstein & Mayer, 1986). The results of a deficiency analysis (Nückles et al., 2004) are the empirical basis for the construction of a learner model that is used to generate immediate differential feedback after the completion of the questionnaire. In addition, the model is used to generate adaptive instructional prompts during production and revision of learning protocols. Prompts referring to strategies or techniques that have not been applied in the past are offered with a greater probability (i.e., more frequently) than prompts referring to techniques that are already in the student’s repertoire.

In this study, we analyzed the impact of these adaptive prompts on the quality of the learning protocols and the learning outcomes in a test of declarative knowledge and a comprehension test. It has, however, been argued that questionnaires on learning strategies are only of limited use for the prediction of actual strategy use (Artelt 1998; Jamison-Noel & Winne, 2003). So, we additionally integrated a test of meta-knowledge similar to a test developed by Schlagmüller, Visé, and Schneider.
(2001) into eHELp. Our modified version of that test examines the students’ knowledge about the appropriateness of certain learning strategies in different learning situations. By including both instruments, we could additionally address the question which of the diagnostic instruments would lead to more effective prompts.

2. METHOD

An experiment was conducted with 81 undergraduate students of psychology. They were paid 10 € each for participation. Two persons had to be excluded due to disregard of the instructions. Ultimately, 79 participants (20 male and 59 female students) with a mean age of 25.7 (range 19 to 50) were included in the study.

As their first task, all participants had to fill out the learning strategy questionnaire and take the meta-knowledge test. In the learning strategy questionnaire the participants had to rate the frequency of their habitual use of different strategies on a four-point scale. In the test of meta-knowledge, the participants read descriptions of learning situations and had to decide on the appropriateness of each of five strategies in a given situation (four-point scale).

After a test of domain knowledge (in the domain of social psychology) all participants read a scientific text about the False-Consensus Effect (extract from Nückles, 2002). Note taking was not allowed. Then all participants wrote a learning protocol. During the writing tasks the learning text was no longer available. After the completion of a first version of the protocols the participants were randomly assigned to one of four experimental conditions. Participants in the no-prompts condition were just asked to revise their protocols (n = 20). Participants in the random-prompts condition (n = 20) received prompts that were randomly selected. Participants in the questionnaire-prompts condition (n = 20) received prompts referring to high-quality strategies that in the questionnaire they had reported using only rarely. Participants in the meta-test-prompts condition (n = 19) received prompts referring to high-quality strategies that they failed to recognize as such in the meta-knowledge test.

After the revision phase all participants had to take a multiple-choice test of declarative knowledge to assess their knowledge of facts (e.g., to identify the right definition of the False-Consensus Effect) and a comprehension test to assess their depth of processing (e.g., the participants were asked to think of fruitful future research questions). After these tests some subjective measures were taken (e.g., on the perceived usefulness or the perceived adaptation of the prompts).

In addition, the quality of each learning protocol was assessed. For that purpose the protocols were evaluated by two independent and trained raters using a category system of Nückles et al. (2004). The protocols were rated based on organization, elaboration, and metacognition. Additionally, the number of right and wrong answers, and the number of words were determined.
3. RESULTS

The groups neither differed significantly in their pretest scores of domain knowledge nor in any of the demographic control variables (i.e., age, number of semesters completed, etc.). In order to compare the effects of the adaptive prompts with the effects of the randomly selected prompts, the questionnaire-prompts condition and the meta-test-prompts condition were grouped into a new adaptive-prompts group and tested against the random-prompts condition.

The quality of the learning protocols was assessed according to the number of words, right and wrong statements, and the extent of organization, elaboration and metacognition. The learning protocols of the adaptive-prompts group showed significantly more elaboration \( F(1, 55) = 5.87, p = .019 \) and metacognitive statements \( F(1, 55) = 8.61, p = .005 \) than the random-prompts group.

In the test of declarative knowledge the adaptive-prompts group \( (M = 5.67, SD = 1.78) \) significantly outperformed \( (t(1, 57) = 1.78, p = .040, d = .49, \text{one-tailed}) \) the random-prompts group \( (M = 4.8, SD = 1.74) \). The adaptive-prompts group also performed somewhat better than the no-prompts condition \( (M = 5.2, SD = 1.95) \) but this difference failed to reach statistical significance \( (t(1, 57) = 1.0, p = .160, \text{one-tailed}) \). Scores in the random-prompts condition were slightly lower than the scores in the no-prompts condition, but as expected they did not differ significantly. It can be stated that the provision of adaptive prompts led to better declarative knowledge when compared to the provision of random prompts.

In the comprehension test the adaptive-prompts group had a higher overall score than the random-prompts condition \( (t(1, 57) = 1.92, p = .030, d = .53, \text{one-tailed}) \) or the no-prompts condition \( (t(1, 57) = 2.6, p = .010, d = .75, \text{one-tailed}) \) respectively. The overall score considers the number of right and wrong answers, and the amount of organization, elaboration, and metacognition. Furthermore, the answers in the adaptive-prompts group showed a significantly higher degree of organization when compared to the random-prompts condition \( (t(1, 57) = 2.36, p = .011, d = .68, \text{one-tailed}) \) or the no-prompts condition \( (t(1, 57) = 1.92, p = .030, d = .54, \text{one-tailed}) \) respectively. The organization score is a measure for the internal and external organization of the protocols. It considers the number of central thoughts and their relations (internal organization) as well as the use of formatting facilities (external organization). The differences in right and wrong answers, elaboration, and metacognition did not reach the significance level. Thus, comprehension was positively affected by adaptive prompts, in particular the organization of the mental representations of the learning material.

Interestingly, adaptive prompts in the questionnaire-prompts condition and in the meta-test-prompts condition had quite a similar effect on the quality of the learning protocols, on the results of the posttests, and on the subjective measures. Another interesting and somewhat puzzling result was obtained in the subjective measures. Although participants did not perceive the adaptive prompts to be more adaptive than the randomly selected prompts, participants in the adaptive-prompts group found the prompts to be considerably more supportive than the participants of the random-prompts group \( (t(1, 57) = -2.51, p = .013, d = .70) \).
In summary, it can be stated that the quality of the learning protocols was improved by adaptive prompts but not by non-adaptive-prompts. In addition, participants that were supported by adaptive prompts during the revision of their learning protocols learned more, both in terms of declarative knowledge and of comprehension. Furthermore, adaptive prompts were judged as being more supportive than non-adaptive prompts. The type of diagnostic instrument (learning strategy questionnaire vs. meta-knowledge test) employed to generate the adaptive prompts did not affect their effectiveness.

4. DISCUSSION

In this experimental study we investigated whether prompts can be made more supportive through their adaptation to the students' needs. A central support procedure in the computer-based environment eHELp is the presentation of prompts that are intended to stimulate organizational, elaborative, or metacognitive activities during the composition of learning protocols. The adaptation of the prompts relies on the results of built-in versions of a questionnaire on learning strategy use, or on a test of meta-knowledge of the adequate use of learning strategies respectively. The questions addressed in this study refer to the potential improvement of the learning protocols as well as to the quality of the learning outcomes.

It was found that the revision of learning protocols was more successful when supported by adaptive prompts, but not when supported by non-adaptive prompts. Both the quality of the learning protocols and the learning outcomes improved significantly. These findings are in line with other findings in the literature (Conati & Van Lehn, 2000; Leutner & Plaas, 1998). However, usually a tremendous effort is required to generate sophisticated and differentiated user models based on a variety of user parameters, particularly in intelligent tutoring systems. Results often lack internal consistency due to a partial overlap of those parameters and due to the difficulties of interpreting user behavior (Schulmeister, 1996). It can be stated that to now, appropriate models of adaptation for cognitive tools and open-ended tasks have not been available (Mandl et al., 1997), or rather are just now beginning to evolve (e.g., direct embedding of assessments in open-ended tasks; Mislevy, Steinberg, Almond, Haertel, & Penuel, 2001). Therefore, our relatively simple way of modeling important user characteristics (a kind of macroadaptation, see Shute & Towle, 2003) seems to be a reasonable approach that requires comparatively little effort for conception, implementation, and application.

Furthermore, the user modeling implemented in eHELp employs well-tried diagnostic instruments to assess important user characteristics, and the prompts presented in eHELp are based on knowledge about learning strategies that were found to be useful in self-guided learning (e.g., to find relations between different subjects, to look for examples of use). Although learning strategy questionnaires were often found to lack the necessary validity to predict the actual use of strategies, they nevertheless seem to be valuable for some special purposes, at least for the adaptive presentation of prompts.
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Not all of the dependent variables changed the way we expected. Organization, for example, was not more evident in learning protocols supported by adaptive prompts than in protocols supported by randomly selected prompts, whereas the answers in the comprehension test showed a considerably higher degree of organization in the adaptive-prompts-condition. That inconsistency could possibly be explained by a lack of explicit translation of thoughts into an external representation. When writing for an audience, experienced writers devote a considerable amount of revision time to the adaptation of their texts to the audience (audience orientation). When writing a learning protocol, the audience consists first and foremost of oneself. Hence, authors might think that there is no need to make everything that goes on in their minds explicit (and they might be right). That is, after all, very similar to the lack of verbalization in think aloud protocols. However, as the comprehension test shows, this lack of “verbalization” of cognitive processes does not necessarily imply that these processes did not take place.

The main focus of our future research will be on the improvement of our computer-supported learning diary approach. However, it also appears to be worthwhile to investigate the use of the described adaptation approach for similar educational contexts, such as the procedural facilitation method (Bereiter, Burtis, & Scardamalia, 1988; Scardamalia, Bereiter, & Steinbach, 1984). This method aims to improve essay writing by providing a pool of supportive prompts. These prompts could possibly be made even more effective by employing the adaptation approach, particularly for inexperienced writers and complex writing assignments.

AFFILIATIONS

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