How to design informative tutoring feedback for multi-media learning

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This paper outlines a conceptual framework for the design of psychologically well-founded informative tutoring feedback forms. This framework is on the one hand based on the large body of research on multiple elaborated feedback types. On the other hand cognitive task and error analyses serve as roots for the development of systematic design strategies. Furthermore, the present paper illustrates how these principles can be applied to the design, implementation and evaluation of informative tutoring feedback for a multimedia learning environment on written subtraction tasks. The impact of the developed informative tutoring feedback forms on learning and motivation was examined in two computer-based learning experiments. The results of these studies show that systematically designed informative feedback has positive effects on achievement and motivation.

Informative feedback has to be considered an important factor in order to support efficient learning processes in computer-based learning or multi-media learning environments. Hence, the effects of multiple types and forms of elaborated feedback have been investigated in a large variety of instructional contexts. Widely used and examined feedback forms are outcome feedback types such as knowledge of result or response (KR, informs whether a response is correct or incorrect), knowledge of the correct response (KCR, provides the correct response or solution) or answer until correct (AUC, provides KR and requires to remain on the same item until it is answered correctly). There also exists a large body of research on elaborated feedback (EF). Unfortunately, the findings on the effects of multiple feedback forms are rather inconsistent (see reviews by Azevedo & Bernard, 1995; Bangert-Drowns, Kulik, Kulik & Morgan, 1991; Butler & Winne, 1995; Clariana, 1993; Mory, 1992, 1996; Mason & Bruning, 2001). In order to derive guidelines for the systematic design of elaborated informative feedback messages this body of research must be considered in detail. However, this detailed consideration is not always possible because it is rather costly. Thus, the design and implementation of informative feedback in multi-media learning environments is often more based on intuition than on psychologically well-founded design principles.

The purposes of the present paper are therefore (a) to outline a conceptual framework for the design of psychologically well-founded informative tutoring feedback messages based on the large body of research on elaborated feedback and on approaches of cognitive task analysis (e.g. Jonassen, Tessmer & Hannum, 1999), (b) to illustrate how to apply these principles in order to design informative tutoring feedback messages for multimedia learning environments, and (c) to summarize the results of two evaluative studies that investigated the impact of the developed informative feedback forms on learning and motivation.

Framework for the design of informative tutoring feedback

Complex elaborated feedback exists in multiple forms and is thus related to a large if not fuzzy set of meanings. Kulhavy and Stock (1989) propose for example to use the term “elaborated feedback” for all types of feedback consisting of more information than KR. There are, however, many different types of information that might be added to KR: explanations for correct or incorrect answers, information about the location of errors, the type of errors, hints about useful sources of information, hints about procedural skills or problem solving strategies, socratic questions etc. In some studies several of these types of information are combined in order to design complex elaborated feedback forms (e.g. Kulhavy, White, Topp, Chan & Adams, 1985; Phye & Bender, 1989). For example, in a text-based instructional context, with multiple choice tasks after each paragraph of the instructional text Kulhavy and his collaborators used an additive strategy to design feedback messages differing in their complexity. The less complex type of feedback was knowledge of the correct response. The most complex type of feedback consisted of knowledge of the correct response, knowledge about the incorrect responses, explanations why the incorrect responses are incorrect combined with a hint to the relevant passage of the text. The post-test consisted of the same multiple choice items as in the instruction. A higher complexity of feedback in these studies was not related to higher performance or to higher efficiency in correcting errors.

The study of Kulhavy and his collaborators attracts the attention to some important problems related to the design of elaborated informative feedback:
In general, elaborated feedback types are compared to simple feedback types such as KR or KCR. Thus, elaborated feedback types are designed combining KCR with additional information. However, providing the correct response of a multiple choice item is just the information necessary to answer this item correctly. Further information (e.g. indicating the incorrect response alternatives and explanations why these alternatives are incorrectly) might be thus considered as irrelevant or even distracting. Furthermore, the elaborated feedback types are often presented in an instructional context that does not require higher order learning but merely the acquisition and retention of declarative knowledge (Smith & Ragan, 1993). Moreover, the same multiple choice items are used in the instructional phase and the post-test. Thus, incorrect answers in the instructional phase can be corrected by simple rote learning of the KCR information. These problems might be even worse if the additional information is selected in a rather intuitive way. In this case it is not guaranteed that the additional information is helpful in the given instructional context. However, additional feedback information that is not really helpful for the identification of the correct response is either processed at a surface-level (Kulhavy et al., 1985) or represents a risk of cognitive overload (Phye & Bender, 1989).
Central issues related to these problems are

1. What factors contribute to the informative value of feedback message?
2. How to select and specify elaborated feedback information that supports the mastery of the learning task(s)?
3. How to provide the selected information in order to promote the mindful processing of this information?

A multi-dimensional view of informative tutoring feedback

Different theoretical frameworks use different types of feedback and attribute different functions to feedback in learning situations. From a behavioral viewpoint feedback is considered to reinforce correct responses. In behavioral learning contexts the focus of interest is therefore more on formal and technical feedback characteristics such as frequency and delay than on the complexity of the feedback contents. Hence, behavioral studies use outcome related feedback types such as knowledge of result or knowledge of the correct response (for a review see e.g. Kulik & Kulik, 1988). From a cognitive viewpoint feedback is considered a source of information necessary for the correction of incorrect responses (e.g. Kulhavy & Stock, 1989). The question of which type of elaborated feedback information is most efficient is of major interest in cognitive feedback studies. However, in most of these studies even elaborated informative feedback has only been conceptualized as seeking to confirm or change a learner's domain knowledge. Feedback models that view feedback in the context of self-regulated learning theorize that the most important function of feedback is tutoring or guiding the learner to regulate the learning process successfully (e.g. Butler & Winne 1995). This tutoring view attracts the attention to the mindful and active processing of (feedback) information, which requires not only domain knowledge and task specific procedural knowledge but also specific and general meta-cognitive knowledge and strategies. As informative tutoring feedback can relate to all of these types of knowledge, there exists a large variety of information that might be provided as feedback.

In order to develop guidelines that help instructional designers in making decision regarding the content, presentation and scheduling of feedback it is therefore crucial to describe carefully the factors that contribute to the informative and tutoring value of a feedback message. On the basis of the large body of research on multiple feedback types we consider the following factors to be relevant to the informative value of a feedback message (see figure 1):

1. the nature and quality of the feedback message,
2. the characteristics of the instructional context, and
3. the individual characteristics of the learner.

The nature and quality of a feedback message is determined by at least three facets of feedback: (a) functional aspects related to instructional goals and objectives (e.g. cognitive functions such as promoting information processing, motivational functions such as reinforcing correct responses or arousing and sustaining effort and persistence); (b) formal and technical aspects related to the presentation of the feedback message (e.g. frequency, timing, mode, amount, form); (c) semantic aspects related to the content of the feedback message.

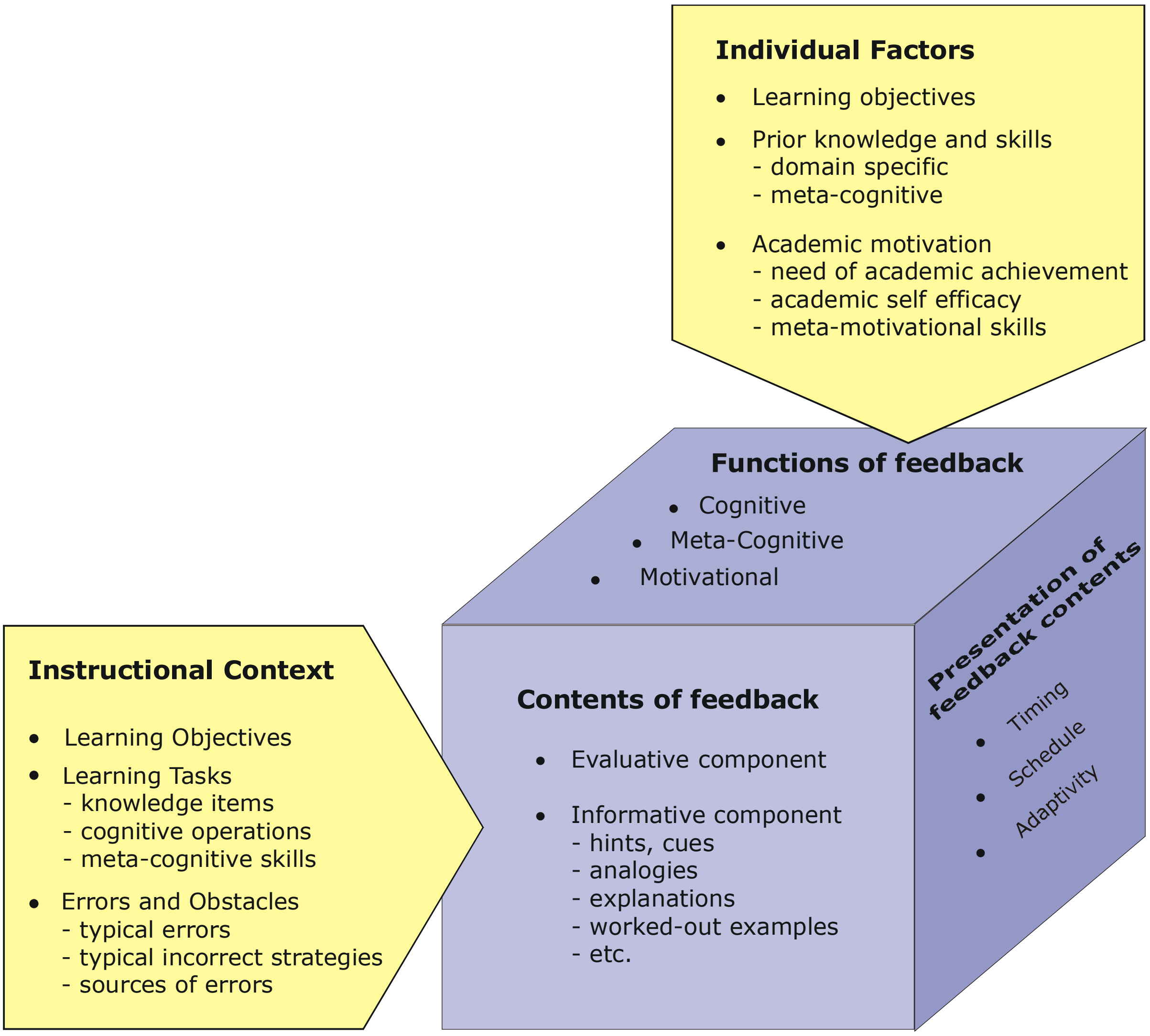

Figure 1: Factors contributing to the informative value of feedback

In general the content of a feedback message may consist of two components (see also Keller, 1983; Kulhavy & Stock, 1989): The first component, the evaluative or in Kulhavy's terms the verification component relates to the learning outcome and indicates the performance level achieved (e.g. correct/incorrect response, percentage of correct answers, distance to the learning criterion). This component is attributed a controlling function (e.g. Keller, 1983). The second component, the informational component consists of additional information relating either to the topic, the task, error(s) or solution(s).

Characteristics of the instructional context that are relevant to the design of an informative feedback message are instructional goals, issues, learning tasks, sources of learning problems and/or errors. These characteristics are relevant to the feedback design because the informative value of a feedback message is only guaranteed if the function, content and form of the feedback message is carefully matched to these characteristics (see also Hannafin, Hannafin & Dalton, 1993; Schimmel, 1988; Smith & Ragan, 1993).

Individual cognitive factors of the learners that are relevant to the design of informative feedback are individual learning objectives, prior knowledge, learning strategies, procedural and meta-cognitive skills. Individual motivational prerequisites are motivational beliefs, need of academic achievement, academic self efficacy and meta-motivational skills. An important conclusion from meta-analyses on multiple informative feedback types is that these individual characteristics might account for the inconsistent findings of the studies (e.g. Azevedo & Bernard, 1995; Bangert-Drowns et al.,1991; Mory, 1992, 1996). Hence, the careful adaptation of the function, content and form of a feedback message to these individual characteristics is of equal importance than the matching to the situational factors of the instructional context.

Selection and specification of informative feedback content

The steps necessary to obtain the factors of the instructional context especially relevant to the design of the feedback content can be derived from knowledge about cognitive task analysis and error analysis (for a detailed description see e.g. Jonassen, Tessmer & Hannum, 1999; VanLehn, 1990):

As shown in figure 2 the first step consists of the selection and specification of learning objectives for the given instructional context (e.g. acquisition of a knowledge domain, mastery of learning tasks, literacy in the given context). This specification of learning objectives in terms of concrete learning outcomes provides the basis for the selection of the feedback content, functions and forms and modi of feedback presentation.

Feedback is presented after the accomplishment of learning tasks. Consequently, learning tasks are especially relevant to the design of feedback. The second step is therefore, to select typical learning tasks and match them to the required learning outcomes.

The third step consists of analyzing the requirements for each type of task. The aim of these task analyses is to identify (a) domain-specific knowledge items (e.g. facts, concepts, events, rules, models, theories), (b) cognitive operations related to these items (e.g. remember, transform, classify, argue, infer) and (c) cognitive and meta-cognitive skills involved in the mastery of the selected learning tasks. The informative components of a feedback message can refer to each of these aspects of a learning task. Hence, the results of these task analyses provide an overview of both task requirements and possible informative components that can be implemented in a feedback message.

Select and specify learning objectives for the given domain of knowledge in terms of concrete learning outcomes

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Select typical learning tasks and match these tasks to the concrete learning outcomes

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Conduct a cognitive task analysis in order to identify
- domain specific knowledge items (e.g. facts, concepts, events, rules, principles, models, theories)
- cognitive operations related to these items (e.g. remember, transform, classify, argue, infer)
- cognitive and meta-cognitive skills necessary for the mastery of the task(s)

↓

Conduct an error analysis in order to identify
- typical systematic errors
- typical incorrect strategies
- misconceptions or sources of errors related to the systematic errors or incorrect strategies

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Select and specify the information that can be provided as feedback if the identified systematic errors occur or obstacles are encountered, e.g.
- cues for retrieving facts, rules, events etc.
- hints providing analogies or case-based examples
- hints on possible sources of information
- hints on successful cognitive strategies
- hints on successful meta-cognitive strategies
- hints on how to correct systematic errors
- explanations to systematic errors
- explanations to cognitive strategies
- explanations to meta-cognitive strategies
- demonstration of the solution by worked-out examples
- demonstration of the correct solution

Figure 2: Selecting and specifying the informative content of feedback using procedures of cognitive task and error analyses

As mentioned above, from a cognitive and from a self-regulated learning viewpoint, elaborated or informative feedback is considered a source of information necessary especially if the learner encounters obstacles or proceeds incorrectly. A next important step for the design of informative feedback is therefore to describe typical errors and typical incorrect steps. Furthermore, it is necessary to identify misconceptions and incorrect or inefficient strategies that can be attributed to the described errors.

The steps described above are essential prerequisites for the last step the selection and specification of "helpful" information. The results of the task and error analyzes provide information which is necessary to select those informative components that match the task requirements. If the major function of the feedback message is tutoring learners to master the given learning tasks and the related requirements feedback should not immediately provide the correct response or explain the correct strategy. This information should only be offered if the learners do not succeed otherwise. Hence, offering adequate tutoring if learners encounter obstacles requires to provide information that supply knowledge on how to proceed without presenting KCR (see also Merrill, Reiser, Ranney & Trafton, 1992). Informative tutoring components that can be selected and designed on the basis of the task and error-analyzes are for example cues for retrieving facts, analogies or worked-out examples, hints on possible sources of information, hints on successful cognitive or meta-cognitive strategies, hints on possible sources of errors or socratic questions (see fig. 2).

Selection and specification of the form and modus of feedback presentation

As illustrated by the study of Kulhavy and is collaborators (1989) selecting appropriate information is a necessary but no sufficient condition for the mindful processing of feedback. Besides the above mentioned individual factors that influence if learners process the feedback information in a mindful way the form and modus of feedback presentation might influence or even inhibit the mindful processing of elaborated feedback. Prior research reveals that inhibitory situational factors are for example presearch availability, simultaneous presentation of elaborated feedback and KCR, no opportunity to apply the feedback to a second or multiple try, no check if mastery level is achieved. Summarizing the findings on these factors we propose to respect the following guidelines in order to select and specify the form and modus of feedback presentation:

1. Do not provide feedback especially KCR before learners have tried to solve the learning tasks on their own. If feedback is available before learners construct their own answers to the learning task, there is a high risk that learners make not enough effort to solve the task on their own. The term presearch availability refers to this problem. In general the results of studies controlling for presearch availability reveal a clear instructional benefit of feedback

compared to a no feedback condition, whereas studies without control for presearch availability provided rather inconsistent results (for a review see Anderson et al., 1971; Bangert-Drowns et al., 1991).

2. Do not immediately combine elaborated feedback components with the correct response or solution (KCR). Prior research shows that this combination of elaborated feedback and KCR results in a low efficiency of the more complex feedback types (c.f. Kulhavy et al., 1985; or Phye & Bender, 1989). Similar to the above mentioned problem of presearch availability, the presentation of elaborated feedback including the correct response increases the risk that learning will be superficial (c.f. Schimmel, 1988).
3. Provide the elaborated feedback information stepwise in manageable pieces and offer the opportunity to apply the information provided on a second or multiple try. Presenting all the information at once may not only result in a superficial treatment of the present information, but also in a cognitive overload (e.g. Mayer & Moreno, 2002; Phye & Bender, 1989). Furthermore, the stepwise presentation of feedback offers not only the possibility to control for slips, but also to provide for each learner only as much information as he or she needs to correct errors or overcome obstacles on their own. Some learners only need to get information about the location or type of their errors, others need also strategic corrective information. Thus, the stepwise presentation of feedback information represents a rather economic way of adapting the feedback information to learners needs.
4. Implement a mastery level in order to check if a specific learning criterion (e.g. the correct application of a procedural rule) is achieved. As learning is considered to be a cumulative process (c.f. Atkinson, 1974) moving on in the learning process before learners have really acquired the knowledge can result in interference effects and frustration. Hence, provide new types of learning tasks only if the prerequisite tasks are mastered.
5. Use the potential of multi-media systems in order to avoid interferences or perceptual and cognitive overload due to modality effects (c.f. Mayer & Moreno, 2002). That means do not automatically provide complex feedback messages as a text. In general complex elaborated feedback messages presented by text need almost the whole space available on a computer-screen. Thus, the working space with the exercise and/or instructional components is covered by the feedback text. In order to avoid this problem we propose to present complex feedback acoustically. The acoustic presentation of feedback offers furthermore, to use the interactivity and multimedia modes of modern information technology (e.g. presenting explanations acoustically and demonstrating the steps of the solution simultaneously by high-lighting or marking the relevant elements in the working space).

Application and evaluation of the design principles

In order to illustrate the application and evaluation of the design principles described above a multi-media learning environment for written subtraction and some experimental results obtained in learning experiments with this environment will be presented in the following sections.

Design of bug-related feedback for written subtraction tasks

Bug-related feedback refers to all types of feedback providing information relevant to the correction of typical systematic errors (c.f. Schimmel, 1988). The purpose of bug-related tutoring feedback is to offer learners as much information as they need in order to correct errors on their own. Using prior research on written subtraction (e.g. Brown & Burton, 1978; Brown & VanLehn, 1980; VanLehn, 1990) and the design principles described above we developed such bug-related tutoring feedback for written subtraction.

Table 1:
Selecting and specifying bug-related information for written subtraction tasks using the design principles based on cognitive task and error analyses

Design principle	**Written subtraction tasks**
Define learning objectives	• Acquire and apply subtraction rules • Acquire and apply meta-cognitive skills for subtraction
Specify concrete learning outcomes	• Mastery of written subtraction tasks requiring the application of the rules with numbers up to 1000 • Mastery of meta-cognitive strategies
Select and match typical learning tasks to the learning outcomes	All kinds of written subtraction tasks with numbers up to 1000 such as 759 - 87
Conduct a cognitive task analysis in order to identify knowledge and skills involved in the mastery of the tasks	• Knowing the subtraction rules • Knowing when and how to apply the rules • Knowing the concept of "zero" • Knowing strategies for error identification • Knowing strategies for error correction
Conduct an error analysis in order to identify typical systematic errors	• Inverted computing = 732 • Ignoring the carry = 772 • Adding the carry to the top digit = 872 • Transferring the zero to the result = 702
Identify potentials sources for the systematic errors	• Top digit is smaller than bottom digit (=> carry of "1") • Top number contains a zero • Bottom number contains a zero • Bottom number contains a blank space • Same digits in one column • Carry in a blank space
Select information that can be provided as feedback if the systematic errors occur	• Indicating the location of errors • Indicating the type of errors • Indicating or explaining the source of errors • Providing a hint to the correct strategy • Explaining the correct strategy
Select information that can be provided as feedback if unsystematic errors occur	• Providing a worked-out example with different numbers in order to demonstrate the correct strategy

The application of the principles for the selection of the bug-related information is summarized in table 1. This application provided at least five different informative components that can be provided in cases of systematic errors. Furthermore, we decided to provide a hint on a worked-out example illustrating the correct subtraction procedure for all unsystematic errors.

Presentation of bug-related feedback in an adaptive, mindful way

Respecting the guidelines for the presentation of tutoring feedback mentioned above, the selected bug-related informative feedback components were implemented in an adaptive tutoring feedback algorithm. Our aim in designing this adaptive tutoring feedback algorithm was to provide strategically useful information for the correction of errors by combining the stepwise presentation of manageable informative feedback components with a multiple try strategy. Thus, the adaptive feedback algorithm presents three levels of feedback as represented in figure 3:

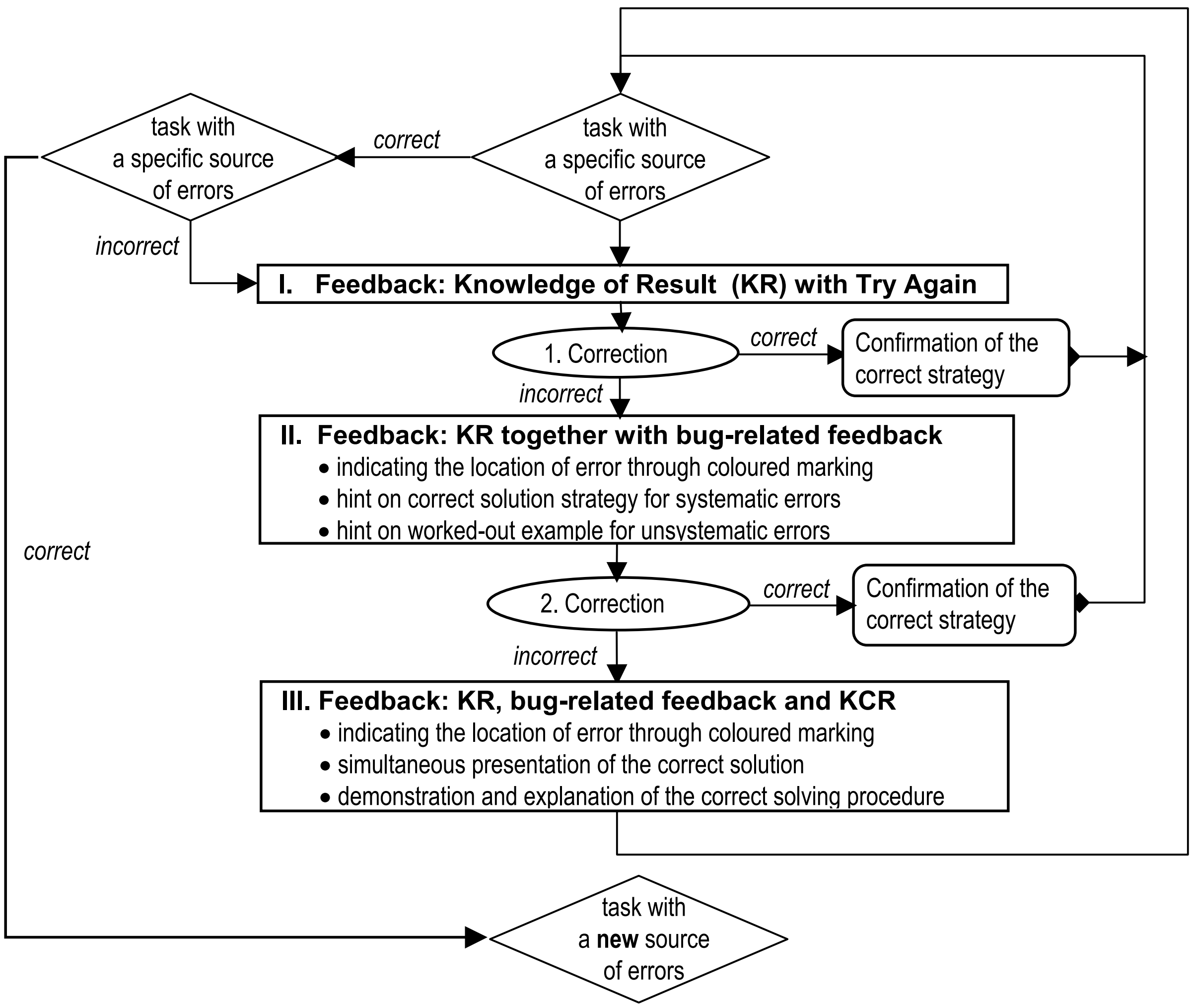

Figure 3: Bug-related tutoring feedback algorithm for written subtraction tasks

First, learners solving a task incorrectly receive knowledge of result (KR) and the recommendation to try again ("Sorry, there is an error, try again"). KR together with a second try enables the correction of slips and is in most cases sufficient for learners who are able to identify and check their own errors.

Second, if the task is solved incorrectly again, KR together with bug-related strategic information is presented. In cases of a systematic error, location of error is indicated through colored marking and a hint on the type and source of error is provided (see figure 3). In cases of an unsystematic error location of error is indicated and a hint to use a worked-out example is provided. In both cases learners are offered the possibility to try again.

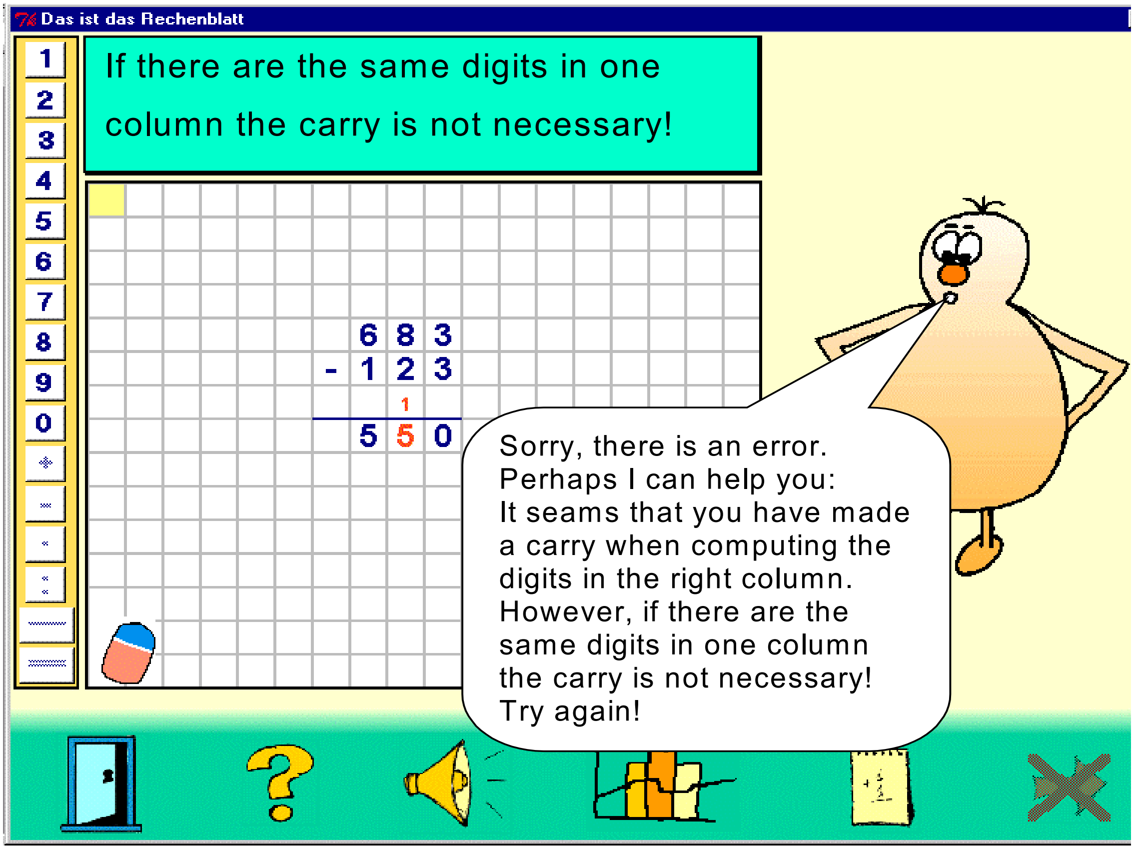

Figure 3: Screen-shot of the written subtraction program with bug-related feedback

Third, if the task is solved incorrectly even a third time, KR together with bug-related strategic information and explanations of the correct solution is provided. Besides the indication of location of error through colored marking, the type and source of error is explained and the correct strategy is demonstrated step by step acoustically and visually.

There are only a few studies using such an elaborated multiple try feedback algorithm and the results of these few studies are inconsistent (for a review see Mory, 1996; Smith & Ragan, 1993). Thus, we conducted two studies in order to evaluate the efficiency of the developed bug-related tutoring feedback algorithm (for a detailed description see Huth & Narciss, 2002). The purpose of these studies was to compare the effects of the bug-related tutoring feedback algorithm to a standard feedback algorithm as it is implemented in most of the computer-based learning or training programs on written subtraction. This standard feedback algorithm presents in a first step the same information as in the first step of the bug-related algorithm (knowledge of result together with a hint to try again). In a second step it provides knowledge of result and the correct solution. It was expected that the informative value of the bug-related feedback algorithm has a more positive impact on achievement and motivation than the standard feedback algorithm: We assumed that bug-related feedback components in contrast to outcome feedback types facilitate successful task completion as well as error correction and thus contribute to more positive motivational beliefs for the given learning situation . These assumptions were supported in both studies: The bug-related feedback algorithm facilitated error correction in the training phase and thus supported the mastery of all types of written subtraction tasks. Furthermore, it contributed to a better performance in a delayed post-test and to more positive motivational beliefs for the given learning situation.

Summary and Conclusion

The present paper describes the development and evaluation of informative tutoring feedback for complex learning tasks. Our goal was to derive general principles for the design of informative feedback on the basis of cognitive task and error analyses. In order to evaluate these principles we applied them to the design of informative feedback forms for typical procedural learning tasks – written subtraction tasks. This application revealed that the cognitive task and error analysis are important prerequisites for the selection and specification of useful information for the given learning tasks: Knowing typical systematic errors as well as the underlying incorrect strategies we were able to develop informative tutoring feedback contents in a systematic way. The effects of these feedback forms on learning and motivation were examined in two computer-based learning experiment. The results of these two studies show that the bug-related tutoring feedback has a significant positive impact on achievement and motivation.

In summary, the present conceptual framework for the design of informative tutoring feedback is characterized by the following aspects:

First, as it is too simplistic to consider the informative value of elaborated feedback merely in terms of the amount of information it contains a multi-dimensional view of feedback is adopted. This multi-dimensional view considers not only the nature and quality of a feedback message, but also situational and individual characteristics of the instructional context as important factors contributing to its informative value. This multi-dimensional view of feedback is in line with the recommendation of researchers to match feedback types and forms carefully to learning tasks and learners' individual needs or characteristics (e.g. Schimmel, 1988; Smith & Ragan, 1993)

Second, the present framework differentiates explicitly three facets of a feedback message, (function, content, form and modus of feedback presentation). In prior feedback models or taxonomies these facets are often confounded (e.g. Kulhavy & Stock, 1989; Schimmel, 1988, Clariana, 1993). However, the clear distinction between these facets is an essential prerequisite for the systematic design of informative or elaborated feedback, because different feedback functions require different contents and different forms of feedback presentation (see also Sales, 1993; Wager & Mory, 1993).

Third, in order to help instructional designers to make decisions about the functions and contents of feedback the present approach suggests to use procedures of cognitive task and error analyses. These cognitive task and error analyses can be used to match systematically informative feedback components to learning objectives, the knowledge and skills necessary for the mastery of the task, and to typical errors or incorrect strategies.

Fourth, besides the decisions about the functions and contents of feedback instructional designers have also to make detailed reflections about the forms and modi of feedback presentation. These decisions regarding the feedback presentation are considered of equal importance as the decisions on the functions and content of feedback. Thus, we used the inconsistent results of prior research on the effects of elaborated feedback to derive guidelines for the presentation of informative feedback components. As we wanted to emphasize the active role of the learner, these presentation guidelines focus on presentation strategies that foster the mindful, active processing of the feedback information (e.g. do not immediately combine knowledge of the correct response and elaborated or strategic informative feedback components, present strategically useful feedback components stepwise and use a multiple try strategy).

Finally, we want to attract the attention to a methodological difference between our evaluative studies and prior studies on multiple informative feedback types that found that more complex feedback types are not more efficient than simple outcome feedback types (e.g. KCR). A conclusion drawn from these prior studies is that it is not worthwhile to develop complex informative feedback types (e.g. Kulhavy et al. 1985; Phye & Bender, 19??). However, these studies investigated only the impact of multiple feedback types on achievement and ignored potential effects on motivation. To our opinion, investigating feedback merely with regard to achievement effects is not sufficient to judge if the systematic design of informative feedback types is too costly or not. Thus, in furthering our understanding of the effects of the developed informative feedback types we examined achievement *and* motivation data in the same experimental context. Indeed, the results of our studies reveal not only achievement effects but also clear motivational effects. These motivational effects might be explained by the fact that the combination of informative tutoring feedback components and multiple try strategies provide success opportunities that can be linked to personal causation (c.f. Keller, 1983, 1987).

Given these results, we want to conclude, that even though the design principles presented in this paper might appear rather costly, they provide a fruitful heuristic framework for the design of informative tutoring feedback types for complex learning tasks. Thus, we suggest to apply the present feedback design principles to a wider variety of learning domains and investigate their effects on achievement and motivation. Future research on this topic is particularly important with regard to the question on how to promote self-regulated learning with modern information technologies.

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